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under Provisions of the Canada-Ontario Agreement
on Great Lakes Water Quality**

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CHEMICAL SEWAGE SLUDGE DISPOSAL ON LAND
(LYSIMETER STUDIES)
VOLUME 1

by

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RESEARCH PROGRAM FOR THE ABATEMENT
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ABSTRACT

A lysimeter project using two typical Ontario agricultural soils was initiated in October, 1972 at the Wastewater Technology Centre, Burlington. The experiment was designed as a randomized block of 22 treatments (11 fertility treatments to each soil). These 22 treatments were replicated three times for a total of 66 lysimeters. The 11 fertility treatments consisted of three chemical sludge types (alum, iron and lime) each at three application rates, plus two controls (with and without NPK fertilizer). Cumulative sludge application rates at the end of 1974 were 700, 1400, and 2100 kg TKN/ha.

Orchard grass was planted in the lysimeters in May, 1973 with subsequent grass harvests monitored for total dry matter yield, plant tissue chemical concentrations and uptakes. Leachate volumes, chemical constituents, and losses were determined, as were microbial concentrations in sludge, leachate, and soil. Chemical constituent material balances were calculated for each treatment.

Increasing rates of sludge application up to a cumulative loading of 2100 kg TKN/ha produced increased yields. The highest grass yields in both 1973 and 1974 were obtained from the iron sludge at the highest application rate. Potassium concentrations in plants grown in 1974 on loamy sand were deficient ($<1.0\%$ K) at the higher sludge loading rates. Concentrations of N, P, Ca, and Mg were adequate, while Zn, Cu, Ni, Cr, Pb, and Cd concentrations were within their respective normal ranges.

Of those leachate chemical constituents for which standards are available, Ca, Mg, Fe, Cu and Zn were within acceptable drinking water limits. Chloride, Na, Mn, Ni, Cr, Pb, and Cd were within acceptable irrigation water limits. Leachate losses of P, K, Al, Fe, Zn, Cu, Ni, Cr, Pb, and Cd were negligible from both soils for all treatments. Nitrogen and Ca leachate losses exceeded those of the other constituents, although no significant correlation was observed between these losses and sludge treatments or loading rates. Leachate microbial analysis during 1973 to 1974 indicated that all of the bacteria observed were of soil origin. The sludge microorganisms were retained in the top 15 cm of both soils.

RÉSUMÉ

Les auteurs ont entrepris, en octobre 1972, au Centre technique des eaux usées de Burlington, l'étude en lysimètre, en Ontario, de l'épandage de trois boues résiduelles sur deux sols cultivés, le sable limoneux et le limon argilo-sableux. Les boues provenaient du traitement chimique des eaux usées à l'alun, au chlorure ferrique et à la chaux. Leur application, en triple, s'est faite à raison de 300, 600 et 900 kg d'azote Kjeldahl total par hectare (kg de NKT/ha), en 1973, et à raison de 400, 800 et 1 200 kg de NKT/ha en 1974. Les auteurs ont parallèlement mené deux expériences avec et sans addition d'engrais chimique N, P, K. L'ensemble de l'étude a nécessité 66 lysimètres.

En mai 1973, ils ont transplanté du dactyle dans les lysimètres. Après l'avoir récolté, ils ont déterminé la quantité de matière sèche, la concentration et l'absorption d'éléments chimiques par le tissu végétal, les volumes des percolats, les composantes et les pertes chimiques de même que la concentration de microbes dans les percolats et dans le sol. Ils ont aussi établi le bilan des éléments chimiques pour chaque épandage.

Pour toutes les boues utilisées, l'apport renouvelé de NKT, jusqu'à un total cumulatif de 2 100 kg de NKT/ha, a entraîné une augmentation de la quantité de matière sèche. L'épandage maximal de boues de chlorure ferrique a permis, à la fois en 1973 et 1974, d'obtenir un rendement optimal de dactyle. Les plantes cultivées en 1974 dans du sable limoneux enrichi au maximum par les boues manquaient de potassium (de 0,6 à 0,7 p. 100 de K). Les éléments essentiels (N, P, Ca et Mg) s'y trouvaient en quantité suffisante et les autres (Zn, Cu, Ni, Cr, Pb et Cd) atteignaient des degrés de concentration normaux.

Parmi les éléments chimiques du percolat pour lesquels on dispose de normes, Ca, Mg, Fe, Cu et Zn se situaient dans les limites acceptables établies pour l'eau potable et Cl, Na, Mn, Ni, Cr, Pb et Cd dans les limites acceptables pour l'eau d'irrigation. Dans toutes les expériences, les pertes de P, K, Al, Fe, Zn, Cu, Ni, Cr, Pb et Cd (en mg/kg de terre) dans les percolats des deux sols ont été négligeables. Même si les pertes de N et de Ca dépassaient les autres, on n'a pu établir de corrélation entre ces pertes et les doses de boues épandues. L'analyse microbienne des percolats a montré que toutes les bactéries recensées en 1973 et en 1974 provenaient de couches présentes dans les sols. Les microorganismes des boues occupaient les 15 centimètres supérieurs des deux sols.

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CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

1. Orchard grass dry matter yields during the second year (1974) exceeded 1973 yields. Yields increased with increasing sludge application rates to both soils for both years. Iron sludge at the highest application rate produced the highest yield. The lowest yields from sludge treatments were obtained from 1973 alum sludge (Point Edwards), containing high lipid and petroleum hydrocarbon concentrations. During 1974, yields from a normal (low lipid) alum sludge (Tillsonburg) were comparable to other sludge sources.
2. Concentrations in plant tissue of N, Na, Cu, and Zn increased with increasing rates of sludge application. Concentrations of K and Mn decreased with increasing sludge rates. Calcium, Mg, Ni, Cr, Pb, and Cd concentrations were generally not affected by sludge type or application rate. The metallic ions, Al and Fe, used for P removal, did increase the concentration of these two elements in plant tissue compared to the lime and NPK control treatments.
3. Potassium concentrations in plants grown during 1974 were deficient (<1.0% K) at the higher sludge loading rates possibly limiting crop yields. Concentrations of the plant nutrients, N, P, Ca, and Mg as well as the heavy metals Cu, Zn, Ni, Pb, Cr, and Cd, were within the normal range.
4. The cumulative (1973 to 1974) plant uptake of N, P, K, Al, Fe, Ca, Zn, Cu, Ni, Cr, Pb, and Cd was greatest at the high rate of iron sludge applied to silt loam. The lowest uptakes occurred at the low rate of alum sludge applied to loamy sand.
5. Nitrate-N, Ca, and Cl concentrations in leachate from both soils were high during the first (1973) growing season, declined during the dormant period (1973 to 1974) and remained low during the second (1974) growing season. Concentrations of $\text{NO}_3\text{-N}$ during the dormant and the following growing season

were less than the drinking water (Canada, 1969) maximum allowable concentrations (10 mg/l) for all treatments. Total organic carbon (TOC) concentrations did not exceed 15 mg/l in 1973 but increased substantially during the 1974 growing season. Total phosphorus concentrations in leachate were generally below 0.2 mg/l.

6. Concentrations of Ca, Mg, Fe, Cu, and Zn in leachate were within the acceptable drinking water limits (Canada, 1969) while chloride, Na, Mn, Ni, Cr, Pb, and Cd concentrations were within irrigation water limits (OMOE, 1974).
7. Cumulative (1973 to 1974) leachate losses of P, K, Al, Fe, Zn, Cu, Ni, Cr, Pb, and Cd were negligible. Leachate N and Ca losses were higher from loamy sand than silt loam.
8. Leachate heterotrophic bacteria identified during 1973 and 1974 were of soil origin ranging from 0.1 to 5.5×10^6 per ml. The sludge microorganisms were retained in the top (15 cm) soil layer, although no coliform bacteria were observed below 7.5 cm.
9. The highest calculated accumulations of N, P, and Al and depletion of K from both soils occurred at the high rate of alum sludge. The highest accumulation of Fe, Zn, Cu, Cr, Pb, and Cd occurred at the high rate of iron sludge. The high rates of alum, iron and lime sludge applications resulted in the highest accumulation of Al, Fe, and Ca, respectively, in both soils. The long term effects of heavy metal accumulations in soils at current rates of application remain to be determined.
10. Cadmium is the heavy metal of greatest concern in these experiments. All sludge types used will double the initial soil Cd content in less than one year at the highest application rate. The relationship between cumulative total and plant available Cd loadings and actual Cd concentrations in plant tissue remains to be determined.

RECOMMENDATIONS

1. The contamination of groundwater by $\text{NO}_3\text{-N}$ in leachate must be avoided by limiting the nitrogen loading (as a sludge or commercial fertilizer) to the nitrogen requirement of the specific crop being grown.
2. A blanket K application of 200 kg K/ha/yr is recommended for all fertility treatments in order to maintain an available N/K ratio of approximately 2:1, and thus avoid future plant K deficiencies.
3. This study should continue at the present annual rates of sludge application until either plant toxicity, depressed crop yield or leachate contamination are observed and evaluated.
4. After one or more of the adverse effects listed in recommendation three have occurred, the lysimeters should be depth sampled to determine heavy metal vertical migration. Sludge amended soil actual material balances should be compared with calculated balances based on leachate and plant uptake loss.

Land application is a common method of sludge disposal in Canada (Black and Schmidtke, 1974), but is not without problems. According to Davies (1971), liquid sludge production in Ontario in 1976 will be nine million tons per year. Phosphorus removal from wastewater using either alum, ferric chloride or lime as precipitating agents is producing increasing quantities of chemical sewage sludges. These sludges applied to land in excessive amounts could result in contamination of water, soil, and plants. These potentially adverse environmental effects need to be assessed.

In 1971, the Government of Canada and the province of Ontario initiated several investigations to study sludge disposal on land. Field trials emphasizing the long term effect of sludge application to various crops and soils are being conducted by the University of Guelph. The Ontario Ministry of Health studied the virological characteristics of sewage sludges. The Regional Municipality of Niagara investigated both surface and subsurface sludge application methods. The Canada Department of Agriculture is conducting laboratory investigations of sludge-soil interactions. The University of Toronto is studying heavy metal analytical methods. To complement these studies, a lysimeter project using two typical Ontario agricultural soils (loamy sand and silt loam) was initiated in October, 1972 by Environment Canada at the Wastewater Technology Centre, Burlington.

Orchard grass is being grown on soils treated with three different chemical sludges at three annual application rates. The objectives of this study are:

1. to investigate crop response to sludge type and application rate;
2. to investigate the effect of sludge type and application rate on the concentration of nutrients, minerals and metals in plant, soil, and leachate; and
3. to monitor the microbial quality of the leachate, and the sludge-soil mixture.

2 LITERATURE REVIEW

2.1 Crop Response to Sludge Application

Merz (1959) found that applications of digested sludge to sandy soils up to 224 tons dry weight solids per hectare/year (tdws/ha/yr) did not impair the growth of barley. Coker (1966) concluded that liquid digested sludge at rates equivalent to recommended chemical fertilizer (NPK) rates produced equal forage yields. King and Morris (1972a and 1972b) found that sludge rates above 40 tdws/ha/yr produced yields of Bermuda grass significantly greater than the control. Hinesly et al (1972) suggested that the nitrogen requirement of a non-leguminous crop could be met by applying liquid sludge at 22 to 34 tdws/ha/yr.

MacLean and Chaisson (1965) reported that aluminum depressed yields of barley grown on Caribou loam (pH 4.9). Lime increased yields when applied with aluminum, but had no effect on yield in the absence of aluminum.

2.2 Concentration of Chemical Elements in Plant Tissue

Griffith et al (1964) found that application of nitrogen (N) fertilizer to orchard grass caused a potassium (K) deficiency. MacLeod and Carson (1966) found that supplementary K applications up to a plant tissue content of 2% K increased grass yields. The protein and nitrate ($\text{NO}_3\text{-N}$) content of the forage was directly proportional to the amount of N fertilizer and inversely proportional to the amount of K fertilizer applied. MacLeod (1965) suggested that to ensure a balanced forage metabolism, 56 kg K/ha/yr and 112 to 224 kg N/ha/yr be applied.

Webber (1972) suggested that the most toxic metals to plants are nickel, copper, and zinc in the ratio 8:2:1, respectively.

2.3 Leachate Chemical Quality

Bolton et al (1970) described a long term controlled drainage investigation growing corn and blue grass on Brookston clay. Concentrations of $\text{NO}_3\text{-N}$ in the leachate of a continuously fertilized corn crop

averaged 8.0 mg/l compared to 1.1 mg/l for a continuously fertilized blue grass crop. Phosphorus (P) concentrations in the leachate from both crops averaged 0.19 mg/l.

Webber and Lane (1969) determined that manure applied to corn grown on medium textured soil at a rate of 174 kg N/ha/yr would result in a 3.2% loss of nitrogen (5.6 kg N/ha/yr) in the leachate.

Page (1974) indicated that concentrations of trace metals in drainage waters of neutral pH are usually less than 0.05 mg/l. In the soil pH range of 5.0 to 9.5, trace elements generally do not exceed 0.25 mg/l.

3 METHODS AND MATERIALS

3.1 Experimental Design

A randomized block design was used consisting of 66 lysimeters (22 treatments each replicated three times). Treatments consisted of two controls (with and without chemical fertilizer NPK) and three chemical sewage sludges each at three rates on two soil types. The chemical fertilizer application rate (kg/ha) was 336N, 112P, and 112K during 1973 and 400N, 133P, and 133K in 1974. The sludge application rates were 300, 600, and 900 kg TKN/ha during 1973 and 400, 800, and 1200 kg TKN/ha in 1974. The sludge application rates were increased in 1974 to allow for closer comparison with the University of Guelph field studies.

3.2 Experimental Facilities

Cylindrical fibreglass lysimeters 30.5 cm in diameter and 183 cm deep were used as soil containers (Figure 1).

The lysimeters were installed in a 3.1 x 15.3 m trailer and projected 7.6 cm above the roof. A rain gauge was installed in the trailer adjacent to the lysimeters. A temperature control unit was installed in the trailer to maintain a winter temperature of $4 \pm 1^\circ\text{C}$ and an ambient soil summer temperature.

3.3 Soils

Loamy sand and silt loam were collected from Cambridge (Hespeler) and Elora, Ontario. The Cambridge soil is of the Caledon sandy loam series and the Elora soil is of the Connestoga sandy clay loam series (Protz, 1975).

3.3.1 Preparation

At both soil acquisition sites, three horizons (A, B, and C) were collected separately. The soils were passed through a Royer soil shredder, air-dried to approximately 5% moisture, then passed through a 0.64 cm stainless steel screen.

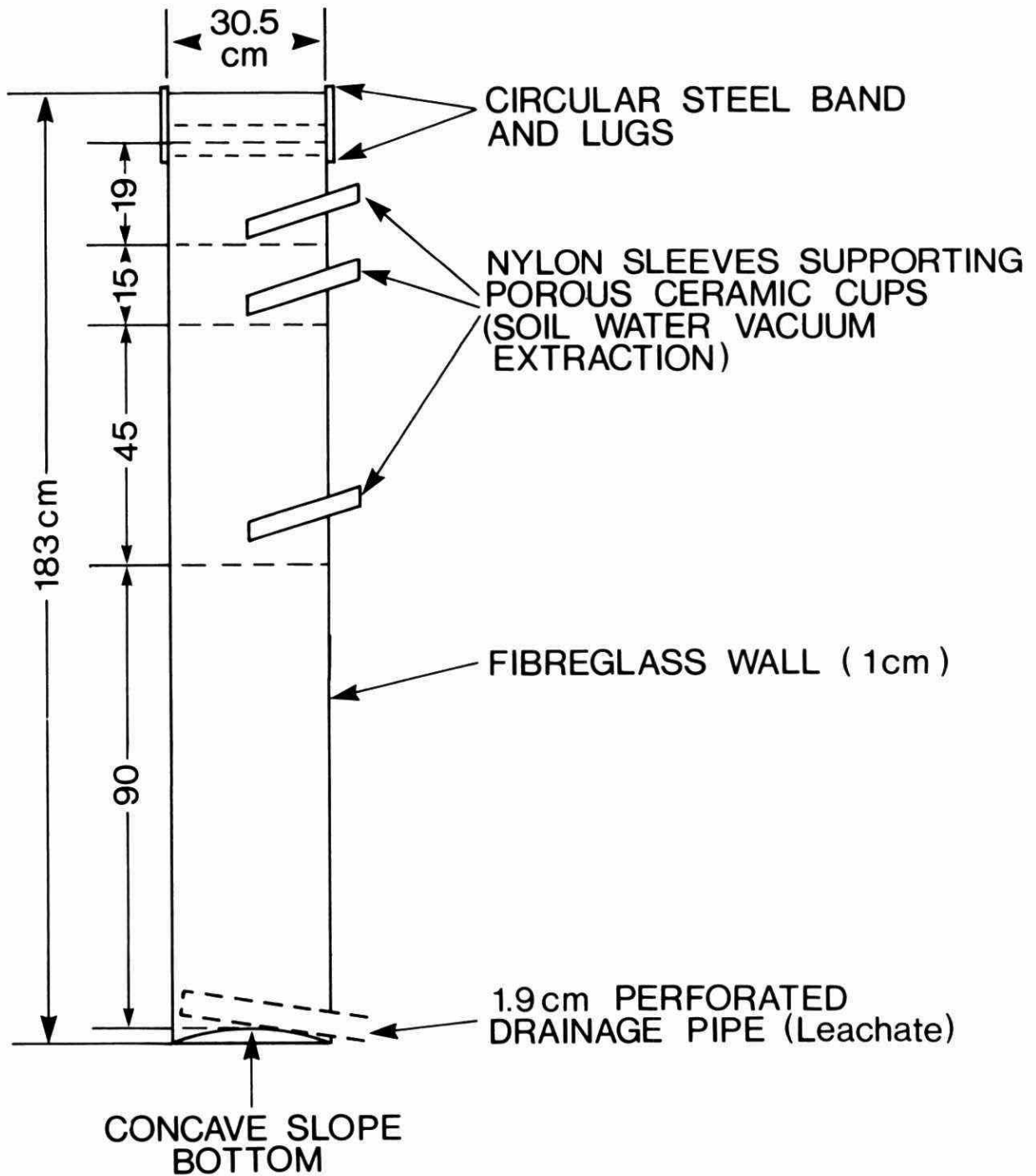


FIGURE 1 TYPICAL LYSIMETER

3.3.2 Profile reconstruction

Silica sand (40 mesh) was used to cover the drainage base of lysimeters to a depth of 10 cm. Each soil horizon was added in a 7 cm layer and packed to the predetermined bulk density (Table 1).

TABLE 1. SOIL TEXTURE AND BULK DENSITY

Soil Type	Horizon	Percentage Particle Size			Bulk Density
		Sand	Silt	Clay	g/cm ³
Loamy Sand (Hespeler)	A	73.5	23.0	3.5	1.4
	B	73.0	27.0	0	1.6
	C	92.0	8.0	0	1.6
Silt Loam (Elora)	A	43.0	44.0	13.0	1.2
	B	42.0	42.0	16.0	1.5
	C	40.0	49.0	11.0	1.7

The soils were saturated with water from the base connections to remove air pockets. Water was allowed to drain from the lysimeters and the soils stabilized under ambient conditions from November, 1972 to May, 1973.

3.3.3 Chemical characteristics

Soil samples were air-dried, screened through a 2 mm sieve, and analyzed (Table 2) according to standard methods (Black, 1965).

3.4 Orchard Grass Crop

Frode variety (*Dactylis glomerata* L.) was chosen for its hardiness and adaptability to most soils. Seedlings for transplanting were grown by a local greenhouse in sterilized soils. Thirteen seedlings per lysimeter were transplanted on May 25, 1973.

TABLE 2. SOIL CHEMICAL ANALYSES*

Constituents	Loamy Sand			Silt Loam		
	Horizons			Horizons		
	A	B	C	A	B	C
TKN	1150	375	120	2000	950	280
NH ₄ -N	4	4	2	6	4	4
Soluble P	0.8	0.3	0.2	0.5	0.2	0.6
Total P	1520	1260	1660	2660	2440	2200
Ca Total	17000	21000	120000	19000	22000	120000
Mg "	4000	5000	1100	7000	9000	33000
Na "	19000	19000	10000	14000	14000	11000
K "	15000	16000	10000	17000	19000	13000
Fe "	23000	23000	14000	34000	35000	21000
Mn "	694	630	404	1040	1000	560
Al "	45000	45000	30000	48000	51000	36000
Zn "	105	72	44	100	90	79
Cu "	13	11	11	20	17	14
Ni "	9	9	5	17	13	9
Cr "	27	26	18	45	35	24
Pb "	18	22	14	16	16	16
Cd "	0.1	0.1	0.1	0.1	0.1	0.1
pH (units)	7.8	7.5	8.6	7.8	8.0	8.6
Organic matter %	2.4	0.9	0.6	3.6	1.6	0.6
C.E.C. meq/100g	9.0	2.9	1.3	18.2	13.3	6.0

* mg/kg dry weight unless otherwise indicated.

The orchard grass was cut four times during each growing season. The grass samples were washed with tap water, rinsed with distilled water, oven dried (70°C), ground to pass through a 60 mesh screen and chemically analyzed.

3.5 Sludges

During 1973 and 1974, anaerobically digested iron sludge was acquired from the North Toronto Water Pollution Control Plant (WPCP) and lime digested sludge was obtained from Newmarket WPCP. Alum digested sludge was obtained from Point Edwards WPCP in 1973 and from Tillsonburg WPCP in 1974.

The sludges were applied each time at 100, 200, and 300 kg TKN/ha three times during 1973 and four times during 1974. The mean sludge compositions are given in Table 3. The loading rates of the various chemical constituents based on TKN are shown in Table 4.

TABLE 3. FLUID SLUDGE COMPOSITION* (1973 AND 1974)

Constituent	1973			1974		
	Alum	Iron	Lime	Alum	Iron	Lime
TKN	1061	2405	923	1864	3679	1360
NH ₄ -N	256	742	207	439	961	326
Total P	1178	1156	461	1735	2499	874
Ca Total	1360	3850	20400	8920	5480	14590
Mg "	297	855	521	931	689	1627
Na "	68	168	144	70	122	113
K "	40	197	74	56	104	50
Fe "	326	5437	838	546	5978	798
Mn "	8	23	26	10	26	40
Al "	3513	1451	316	6873	1768	1377
Cu "	25	96	15	31	112	17
Zn "	39	199	61	33	175	41
Ni "	1.6	3.4	2.3	0.4	1.0	0.4
Cr "	7.4	42.0	3.5	6.4	41.0	1.7
Pb "	13.0	87.0	12.0	10.0	127.0	10.0
Cd "	0.4	1.4	0.6	0.5	1.9	0.5
Total Lipids	6200	700	277	150	-	-
Petrol. Hydrocarb.	3724	281	83	-	-	-
Total Solids %	4.6	6.9	9.1	3.8	7.3	3.3
pH (units)	6.8	7.2	7.2	7.1	7.0	7.0

* mg/l unless otherwise indicated.

TABLE 4. SLUDGE CONSTITUENT LOADINGS* AT THE LOWEST RATES**
(1973 AND 1974)

Constituent	1973			1974		
	Alum	Iron	Lime	Alum	Iron	Lime
TKN	300	300	300	400	400	400
NH ₄ -N	72	101	77	95	105	93
Total P	335	136	136	371	274	247
Ca Total	380	617	7078	2028	608	3984
Mg "	83	146	175	215	78	397
Na "	19	24	53	15	13	30
K "	11	28	23	12	11	14
Fe "	92	750	254	120	654	223
Mn "	2	3	8	2	3	12
Al "	992	199	88	1577	197	332
Cu "	7.0	13.2	5.1	6.5	8.6	5.4
Zn "	11.0	27.0	23.0	9.0	19.0	12.0
Ni "	0.5	0.4	0.7	0.1	0.1	0.1
Cr "	2.1	5.4	1.1	1.4	4.4	0.5
Pb "	3.6	11.7	3.8	2.2	14.0	2.5
Cd "	0.1	0.2	0.2	0.1	0.2	0.1
Total Lipids	1752	79	75	33	-	-
Petrol. Hydrocarb.	1051	32	23	-	-	-
Total Solids (t/ha)	13	10	30	8	9	11
Liquid Sludge (m ³ /ha)	284	136	356	218	123	331

* kg/ha unless otherwise indicated.

** Maximum loadings three times the values listed.

3.6 Leachate

From mid-June, 1973 until mid-April 1974, leachate was collected monthly and stored at 4°C until analyzed. The frequency of collection during the 1974 growing season was altered to coincide with the harvest and sludge application dates. Leachate volume, pH and conductivity were

measured prior to filtration through a 0.45 micron filter. Chemical analysis of leachate was done according to standard methods (APHA, 1971).

3.7 Microbiological Analysis

Samples of sludge, soil and leachate were collected for microbiological analysis. Grab samples of the surface soils (A horizon) were taken prior to sludge application. Sludge amended soil samples (2 cm cores) to a depth of 61 cm were taken in April, 1974 for microbial analysis. These cores were subsectioned into 2.5, 7.5, 15.0, 25.0, 37.5, and 60.0 cm depth fractions for the study of microbial vertical movement in the soils.

One gram soil samples were weighed and then washed with 9 ml of sterile distilled water into 90 ml of 0.01M phosphate buffer (pH 7.0). This mixture was homogenized for one minute prior to plating. Enriched nutrient agar used for bacterial population enumerations had the following ingredients (g/l): nutrient agar, 23; glucose, 0.2; sodium acetate, 0.2; yeast extract, 0.2; peptone, 0.2.

The predominant bacterial isolates found in the soils were *Alcaligenes*, *Acinetobacter*, *Flavobacterium*, *Pseudomonas*, *Bacillus*, *Aeromonas*, *Vibrio*, and *Chromobacter*. The silt loam contained 4.0×10^8 heterotrophic bacteria per gram of soil (dry weight), whereas the loamy sand contained 1.7×10^8 .

The predominant genera of aerobic heterotrophic bacteria found in the three sludges are given in Table 5 and bacterial densities are given in Table 6.

TABLE 5. PREDOMINANT BACTERIAL GENERA IN SLUDGES (1973)

Alum Sludge	Iron Sludge	Lime Sludge
Alcaligenes Flavobacterium Acinetobacter Pseudomonas Aeromonas - Escherichia Enterobacteriaceae sp.	Alcaligenes Flavobacterium Acinetobacter Pseudomonas - Aerobacter Escherichia -	Alcaligenes Flavobacterium Acinetobacter - - Aerobacter Escherichia Enterobacteriaceae sp.

TABLE 6. BACTERIAL DENSITIES* IN SLUDGES (1973)

Sludge Types	Bacterial Types	June 5	July 27	Sept. 5	Mean
Alum Sludge	Heterotrophic (20°C)	8.8×10^9	7.5×10^9	2.7×10^{10}	1.4×10^{10}
	Coliform MF **	1.1×10^6	8.7×10^5	1.5×10^6	1.2×10^6
	Fecal Coliform MF	7.0×10^4	1.0×10^5	5.0×10^5	2.2×10^5
	Fecal Strep. MF	4.0×10^4	2.0×10^4	5.0×10^4	3.7×10^4
Iron Sludge	Heterotrophic (20°C)	2.7×10^{10}	2.2×10^{10}	4.1×10^{10}	3.0×10^{10}
	Coliform MF	2.0×10^4	9.0×10^4	6.0×10^5	2.4×10^5
	Fecal Coliform MF	1.0×10^4	3.0×10^4	8.0×10^4	4.0×10^4
	Fecal Strep. MF	2.0×10^4	1.0×10^4	3.0×10^3	1.1×10^4
Lime Sludge	Heterotrophic (20°C)	1.2×10^{10}	3.2×10^{10}	1.1×10^{10}	1.8×10^{10}
	Coliform MF	2.5×10^6	7.5×10^5	3.0×10^5	1.2×10^6
	Fecal Coliform MF	4.5×10^5	1.0×10^4	ND	2.3×10^5
	Fecal Strep. MF	3.4×10^5	5.0×10^4	3.0×10^3	1.3×10^5

* Number per 100 ml.

** MF = millipore filter.

ND = not determined.

4 RESULTS AND DISCUSSION

4.1 Crop Yields

The orchard grass was first harvested on June 26, 1973, 21 days after the first application of sludges and commercial fertilizer. Successive cuts were made on July 23, August 31, and November 5. All cuts (with the exception of the last) were made at the early boot (preheading-plant development) stage, to ensure optimal plant growth. Orchard grass yields for 1973 are presented in Table 7.

The silt loam NPK treatment increased yield by 58% compared to the control, versus a 156% increase for the same treatment on loamy sand. The highest sludge loading rate on loamy sand produced yields which were 66%, 173%, and 149% greater than the control compared to yields from silt loam which were 22%, 81%, and 72% greater than the control for alum, iron, and lime sludges, respectively. Yields exceeding NPK treatment were obtained from the highest rate of iron sludge on loamy sand and the highest iron and lime sludge treatments on silt loam.

During the second growing season, the orchard grass was harvested on May 31, 1974, 35 days after the first sludge application. Successive cuts were harvested on July 2, August 6, and September 18. Growth development was at the early boot stage for all cuts except the last which was harvested early because of visible K deficiency. Orchard grass yields for 1974 are summarized in Table 8.

The highest sludge loading rates produced the highest yields as in 1973. Yield increases compared to control at the highest loading rates on loamy sand were 461%, 510%, and 424%, compared to silt loam yield increases of 255%, 291%, and 233% for alum, iron, and lime sludges, respectively. Although the percentage yield increases compared to the control were highest on loamy sand, the absolute dry weight increases were highest on silt loam.

All of the sludge treatment yields at the highest rates exceeded the NPK treatment on both soils in 1974. Increased yields in 1974 were a result of both higher loading rates and the residual effects of the 1973 sludge application. The iron sludge at the highest application rate produced the highest yield on both soils.

TABLE 7. ORCHARD GRASS YIELDS* (1973)

Treatment	Rate (kg TKN/ha)	Loamy Sand					Silt Loam				
		Cut 1	Cut 2	Cut 3	Cut 4	Total	Cut 1	Cut 2	Cut 3	Cut 4	Total
Control	0	1.74	1.24	0.80	0.48	4.26	2.18	2.86	2.31	1.03	8.38
NPK	N - 336 P - 112 K - 112	1.75	2.77	3.94	2.46	10.92	2.38	3.48	4.66	2.72	13.24
Alum Sludge	300	1.85	1.28	1.02	0.93	5.08	2.52	2.84	2.23	1.25	8.84
	600	1.66	1.50	1.43	1.23	5.82	2.50	3.08	2.39	1.61	9.58
	900	2.00	1.70	1.88	1.51	7.09	2.17	3.23	2.91	1.89	10.20
Iron Sludge	300	1.84	1.84	2.09	1.36	7.13	2.40	3.17	3.58	2.10	11.25
	600	1.76	2.12	3.08	1.84	8.80	2.14	3.13	4.46	2.82	12.55
	900	2.05	2.53	4.21	2.85	11.64	2.15	3.65	5.49	3.89	15.18
Lime Sludge	300	1.77	1.72	1.78	0.91	6.18	2.85	3.34	3.01	1.91	11.11
	600	2.04	2.21	2.82	1.56	8.63	2.74	3.62	4.09	2.28	12.73
	900	1.86	2.63	3.88	2.22	10.59	2.18	3.85	5.30	3.10	14.43

* tons dry matter/ha.

TABLE 8. ORCHARD GRASS YIELDS* (1974)

Treatment	Rate (kg TKN/ha)	Loamy Sand					Silt Loam				
		Cut 1	Cut 2	Cut 3	Cut 4	Total	Cut 1	Cut 2	Cut 3	Cut 4	Total
Control	0	0.77	0.65	0.69	0.41	2.52	2.12	1.23	1.19	0.72	5.26
NPK	N - 400 P - 133 K - 133	3.09	2.74	3.58	3.26	12.67	4.04	3.97	4.07	3.10	15.18
Alum Sludge	400	2.29	1.66	2.27	1.68	7.90	3.71	2.54	2.75	1.85	10.85
	800	3.40	2.65	3.40	2.68	12.13	6.38	3.54	3.65	2.57	16.14
	1200	3.88	3.33	3.67	3.25	14.13	6.36	4.41	4.39	3.51	18.67
Iron Sludge	400	1.77	1.99	2.34	1.66	7.76	4.11	2.63	2.74	1.76	11.24
	800	3.10	3.08	3.05	2.66	11.89	4.23	3.79	3.82	2.70	14.54
	1200	3.87	3.70	4.18	3.61	15.36	6.90	4.97	4.69	3.98	20.54
Lime Sludge	400	1.56	1.66	1.95	1.64	6.81	3.98	2.39	2.32	1.81	10.50
	800	2.43	2.85	2.77	2.48	10.53	5.00	3.70	3.05	2.45	14.20
	1200	2.98	3.63	3.51	3.09	13.21	5.45	4.49	3.66	3.39	16.99

* tons dry matter/ha.

Total dry matter yields (1973 and 1974) and statistical significance are summarized in Table 9. There was no significant interaction between soil types and treatments. Yield differences for all other variables were significant at 0.01 probability by "F" test, with the exception of sludge types x rate which were significant at 0.05 probability in 1974.

Increasing sludge application rates significantly increased yields from both soils for all sludge types. Although nitrogen stimulated potassium deficiency (particularly at the higher sludge application rates) may have limited yields of the 1974 crop, yields from all sludge treatments were generally higher during 1974 than 1973. The highest application rate of iron and lime sludges produced significantly higher cumulative yields than the NPK treatment on both soils.

Yields were higher than expected under normal field conditions for the following reasons:

1. The forage overhang spread about 5 cm beyond the lysimeter edge thus increasing plant exposure to light.
2. Ample irrigation moisture was always available.
3. Manual harvesting minimized loss of plant material.

Limited yield response during 1973 from Point Edwards alum sludge treatments is attributed to unusually high lipid (petroleum hydrocarbon) concentrations of 6200 mg/l. Yield response from the 1974 Tillsonburg alum sludge treatments (150 mg/l lipids) was much higher than from the Point Edwards sludge treatments. Orchard grass from the 1973 alum sludge treatment showed some yellowing of leaf tips by the second cut and intense yellowing by the fourth cut. According to Baker (1970) this could indicate petroleum hydrocarbon toxicity.

4.2 Plant Chemical Constituents

The concentration and uptake of 15 chemical elements was determined including nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sodium (Na), iron (Fe), manganese (Mn), aluminum (Al), copper (Cu), zinc (Zn), nickel (Ni), chromium (Cr), lead (Pb) and cadmium (Cd). Concentrations of these elements in plant tissue can

TABLE 9. ORCHARD GRASS YIELDS (1973 AND 1974)¹

Treatments	Rates (kg TKN/ha)	1973		1974		1973+1974	
	1973 1974	Loamy Sand	Silt Loam	Loamy Sand	Silt Loam	Loamy Sand	Silt Loam
Control	0	4.26	8.38	2.52	5.26	6.78	13.64
NPK	336•112•112	10.92	13.24	12.67	15.18	23.59	28.42
	400•133•133						
Alum Sludge	300 400	5.08	8.84	7.90	10.85	12.98	19.69
	600 800	5.82	9.58	12.13	16.14	17.95	25.72
	900 1200	7.09	10.20	14.13	18.67	21.22	28.87
Iron Sludge	300 400	7.13	11.25	7.76	11.24	14.89	22.49
	600 800	8.80	12.55	11.89	14.54	20.69	27.09
	900 1200	11.64	15.18	15.36	20.54	27.00	35.72
Lime Sludge	300 400	6.18	11.11	6.81	10.50	12.99	21.61
	600 800	8.63	12.73	10.53	14.20	19.16	26.93
	900 1200	10.59	14.43	13.21	16.99	23.80	31.42
Standard Error ±		0.39		0.52		0.70	
Treatments		**		**		**	
- Control vs Others		**		**		**	
- NPK vs Sludges		**		**		**	
- Sludge Types		**		**		**	
- Sludge Rates		**		**		**	
- Sludge Types x Rate		**		*		**	
Soil Types		**		**		**	
Treatments x Soil Types		NS		NS		NS	

¹ tons dry matter/ha.

* Significant at 0.05 Probability (F test).

** Significant at 0.01 Probability (F test).

NS Non Significant.

range from deficient through adequate to toxic. Concentration ranges will vary with plant species and variety.

Statistical analyses of chemical constituent concentrations for each individual cut per growing season were too numerous for inclusion in this report. Arithmetic means of all cuts harvested for each growing season were, therefore, used to assess trends.

Mean concentrations of N, P, K, Ca, Mg, Na, Fe, Mn, Al, Cu, Zn, Ni, Cr, Pb and Cd in orchard grass harvested from both soils in 1973 and 1974 are given in Tables 26 to 40 (Appendix I). Orchard grass chemical constituent concentrations from sludge treatments are compared with non-sludged controls with and without NPK fertilizer and with normal ranges in plants (Table 10).

The orchard grass chemical concentrations were within the normal range except for K, Fe, Al and Pb. No toxic effects were observed for any constituent. Concentrations of K were lower than normal in 1973 and extremely deficient in 1974 on both soils. Iron concentrations were generally higher than normal ($>250 \mu\text{g/g}$) from iron sludge applications compared to alum and lime sludges. It should be noted, however, that non-fertilized control Fe concentrations also exceeded the normal range. Concentrations of Al were higher than normal from alum sludge treatments in 1973 on loamy sand. Concentrations of Pb from iron sludge treatments slightly exceeded the normal range reported in the literature.

Total Kjeldahl nitrogen concentrations from the highest rate of iron sludge application on both soils equalled the NPK treatment, but were less than the 3.0% suggested as adequate by Kresge and Younts (1963) and MacLeod (1965). Nitrogen uptake increased with increasing rates of sludge application ranging from 140 kg N/ha (untreated control) to 950 kg N/ha (iron sludge on silt loam) over two growing seasons (Figure 2).

Phosphorus concentrations in plant tissue increased in 1974 compared to 1973 on both soils from all sludge treatments (Table 27). During 1974, P concentrations ranged from 0.25 to 0.38% and were adequate for orchard grass (Reid et al, 1967).

TABLE 10. ORCHARD GRASS CHEMICAL CONSTITUENTS COMPARED TO NORMAL RANGE IN PLANTS (1973 AND 1974)

Constituents	Units	Concentrations in Orchard Grass (Controls) (Sludge Treatments)		Normal Range (from the Literature)	References
N	%	1.98 - 2.76	1.93 - 2.90	2.0 - 3.1	1
P	"	0.17 - 0.30	0.19 - 0.38	0.23 - 0.28	2
K	"	1.84 - 3.10	0.60 - 3.07	1.0 - 2.5	3
Ca	"	0.48 - 0.70	0.51 - 0.71	0.21 - 1.00	4
Mg	"	0.29 - 0.38	0.31 - 0.40	0.31 - 0.50	4
Na	"	0.03 - 0.49	0.03 - 0.80	0.46 - 1.95	5
Fe	µg/g	219 - 317	181 - 412	50 - 250	6
Mn	"	114 - 245	57 - 201	20 - 500	6
Al	"	63 - 185	57 - 881	300	7
Cu	"	5.2 - 8.0	5.3 - 14.8	5 - 20	6
Zn	"	36 - 53	31 - 112	25 - 150	6
Ni	"	1.0 - 1.4	0.7 - 1.6	0.1 - 1	8
Cr	"	0.5 - 1.9	0.5 - 1.8	0.74 - 2.07	8
Pb	"	5.7 - 9.9	5.7 - 16.1	0.1 - 10.0	8
Cd	"	0.16 - 0.74	0.17 - 0.63	0.2 - 0.8	8

1. Kresge and Younts (1963).
2. Reid et al (1967).
3. Robinson et al (1962).
4. Neubert et al (1969).
5. Bower and Wadleigh (1949).
6. Jones (1972).
7. Jones (1961).
8. Allaway (1968).

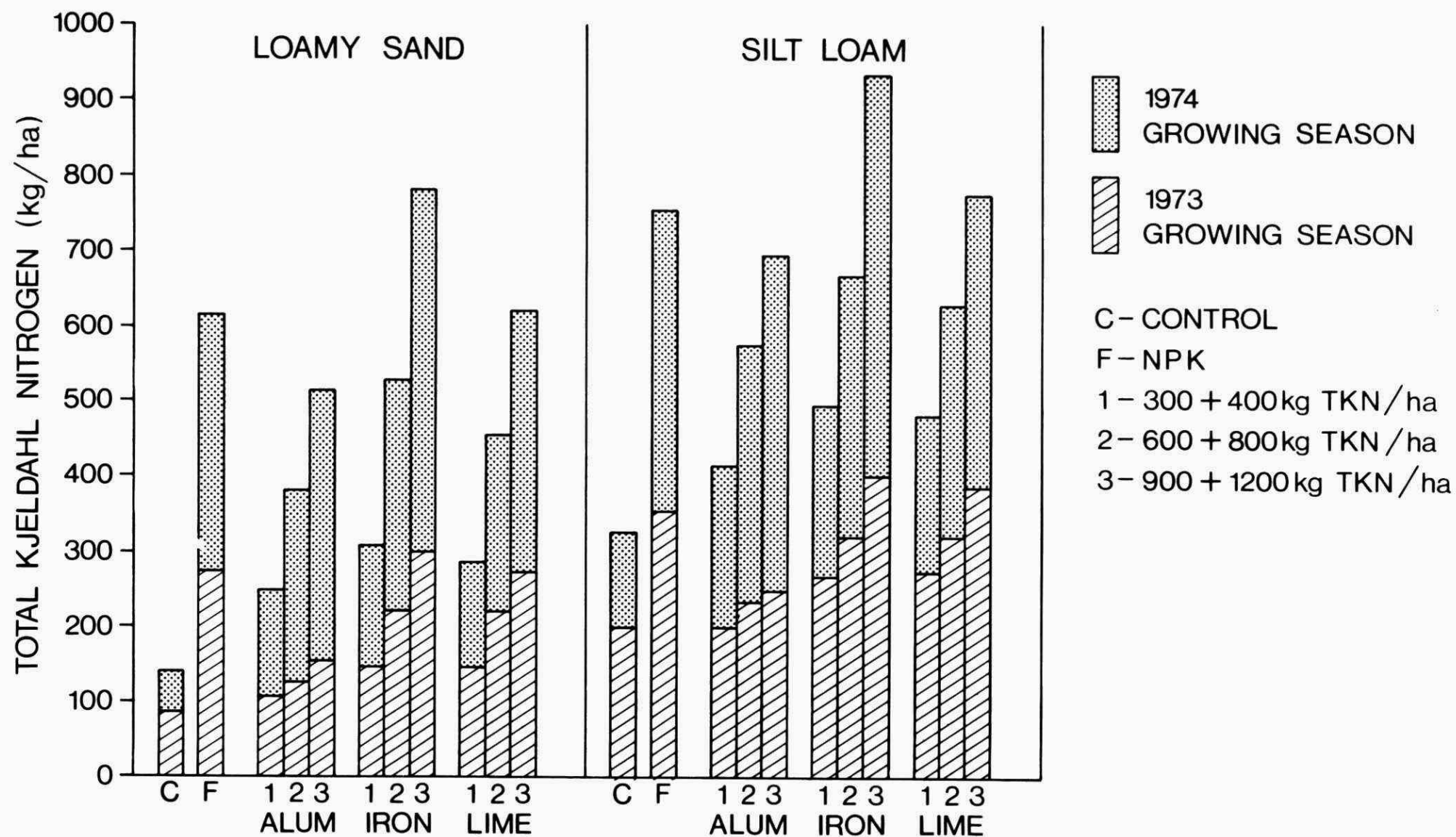


FIGURE 2 UPTAKE OF NITROGEN BY ORCHARD GRASS 1973 - 74

Potassium concentrations in plant tissue dropped from a minimum of 1.84% in 1973 (loamy sand) to a low of 0.6% in 1974 (Table 28). Serious K deficiencies were observed in 1974 (Robinson et al, 1962; and Griffith et al, 1964). Sludge loading N/K ratios ranged between 11:1 and 36:1 compared to a maximum recommended N/K ratio for orchard grass of 4:1 (MacLeod, 1965). Plant uptake of K from sludge treatment to silt loam exceeded 300 kg K/ha/yr (Figure 3), compared to a maximum of only 84 kg K/ha/yr applied at the highest sludge loading rate (Table 4).

Calcium and magnesium concentrations in plant tissue were not affected by sludge rates (Tables 29 and 30). Plant uptake of Ca or Mg was not significantly influenced by the high Ca loadings from lime sludge.

Sodium concentrations in plant tissue were inversely proportional to K concentrations (Table 31). The highest Na concentration (0.80%) observed in 1974 was from the highest rate of lime sludge. These concentrations were within the normal plant range (Bower and Wadleigh, 1949).

Iron concentrations in plant tissue ranged from 181 to 412 µg/g from all sludge treatments (Table 32). The iron sludge treatment and non-fertilized control Fe concentrations were above the normal range (Jones, 1972).

Manganese concentrations in plant tissue were inversely proportional to sludge application rates (Table 33). These concentrations ranged from 57 to 201 µg/g and were within the normal plant range (Jones, 1972).

Aluminum concentrations in plant tissue ranged from 57 to 881 µg/g from all sludge treatments (Table 34). Concentrations of Al from 1973 alum sludge treatments on loamy sand exceeded the 300 µg/g value found to be non-toxic to clover (Jones, 1961). The 1974 Al concentration did not exceed 114 µg/g for any sludge treatment.

Copper concentrations in plant tissue ranged from 5.3 to 14.8 µg/g from all sludge treatments (Table 35) and were within the normal range (Jones, 1972). Concentrations of Cu generally increased with increasing sludge application rates.

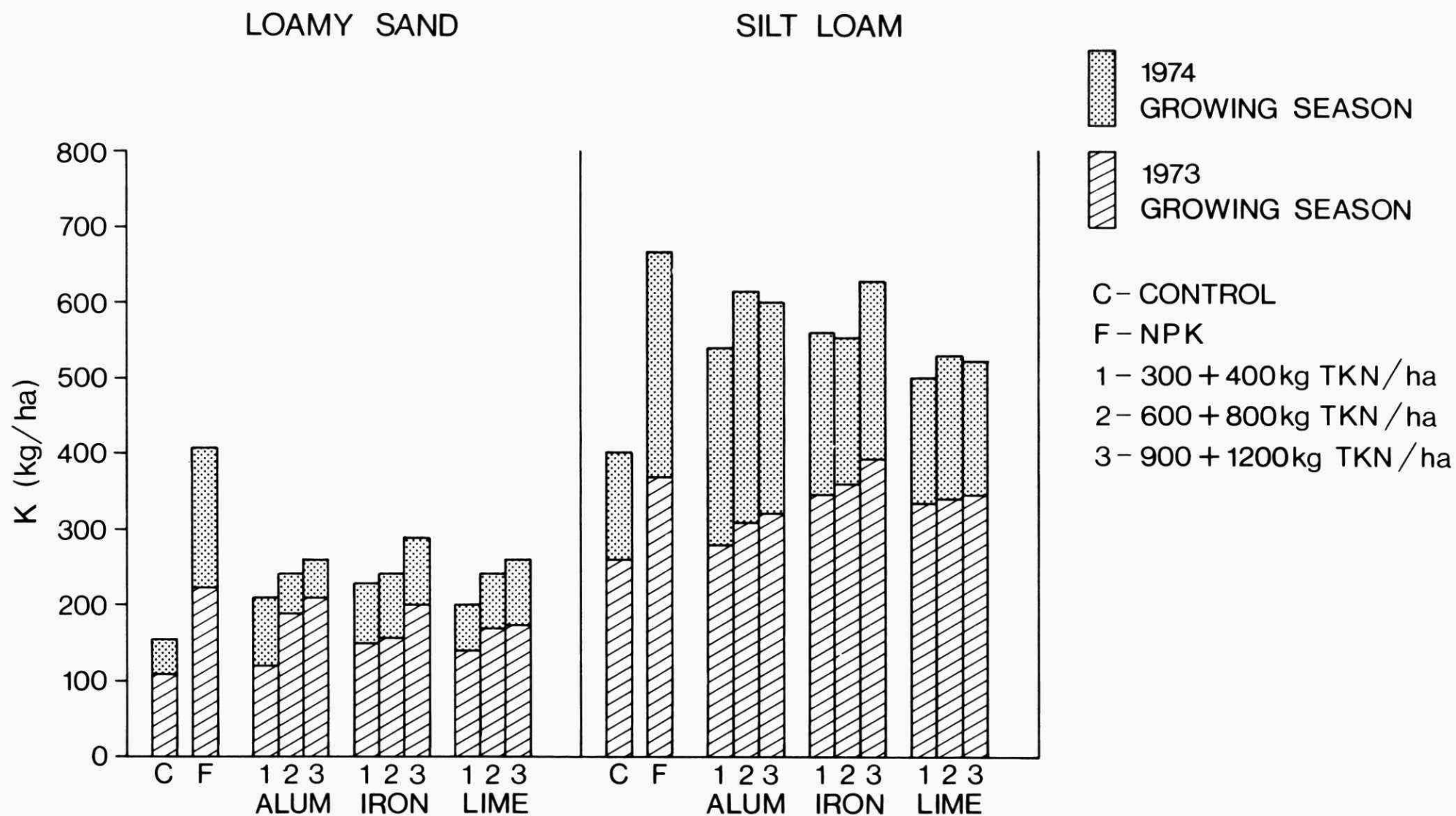


FIGURE 3 UPTAKE OF POTASSIUM (K) BY ORCHARD GRASS 1973-74

Zinc concentrations in plant tissue ranged from 31 to 112 $\mu\text{g/g}$ for all sludge treatments (Table 36) and were within the normal range (Jones, 1972). Zinc concentrations increased with increasing application rates in 1974 on both soils, but were generally higher on loamy sand.

Nickel concentrations in plant tissue ranged from 0.7 to 1.6 $\mu\text{g/g}$ (Table 37) for all sludge treatments and were within the normal range (Allaway, 1968). Concentrations of Ni in plants from sludged soils were generally lower than from the untreated controls.

Chromium concentrations in plant tissue from all sludge treatments were higher in 1974 than 1973, ranged from 0.5 to 1.8 $\mu\text{g/g}$ (Table 38) and were within the normal range (Allaway, 1968).

Lead concentrations in plant tissue from all sludge treatments ranged from 5.7 to 16.1 $\mu\text{g/g}$ (Table 39). The normal range of Pb reported in the literature is 1 to 10 $\mu\text{g/g}$ (Allaway, 1968). Concentrations of Pb increased with increasing sludge application rates in 1974.

Cadmium concentrations in plant tissue from all sludge treatments ranged between 0.15 to 0.63 $\mu\text{g/g}$ (Table 40). These concentrations were within the normal range (Allaway, 1968).

In summary, N, Na, Cu, and Zn concentrations in orchard grass increased while K and Mn concentrations decreased with increasing rates of sludge application to both soils for both years.

Phosphorus, Ca, Mg, Al, Fe, Ni, Cr, Pb, and Cd concentrations were not consistently affected by sludge application rates. The chemical used for P removal (alum, iron or lime) did increase the concentrations of Al, Fe or Ca, respectively.

4.3 Leachate

The concentration of chemical constituents in leachate depends primarily on the flow rate of water through soil. The flow rate is determined by plant evapotranspiration and soil characteristics. Silt and clay soils have greater water holding capacity than highly permeable sandy soils. Soils with lower permeability retain soluble elements in the root absorption zone for longer periods, thus allowing for increased plant uptake.

Volumes of leachate collected during the growing and dormant seasons included periods when no leachate was collected at all. Statistical analysis of separate leachate collection periods has, therefore, been restricted to seasonal cropping and dormant periods. During 1974, replicates were composited when necessary to provide the minimum volume required for chemical analysis. This precluded meaningful statistical analysis of leachate constituents. Trend assessment and comparison with existing water quality criteria are, therefore, based on arithmetic seasonal means.

4.3.1 Leachate volume

The volumes of leachate and their statistical analysis are summarized in Table 11. Water applied (irrigation plus precipitation) during 1973 growing season (June to November) equalled 10,900 m³/ha (1090 mm) compared to 4870 m³/ha (487 mm) during the dormant season (November, 1973 to April, 1974), and 8800 m³/ha (880 mm) during the second growing season (April to September, 1974). The lysimeters were irrigated as required to maintain soil moisture at one-third field capacity or greater.

Leachate volumes from sludge treatments were significantly different (0.01 probability) for both growing seasons except 1973 sludge types x rate and 1974 NPK vs sludge treatments which were significant at P=0.05. During the dormant season, differences due to soil type, sludge rates and sludge types x rate were not significant. Cumulative leachate volumes for both growing and dormant periods were significantly different at P=0.01 for all variables.

During the growing seasons, the volumes leached were inversely proportional to the crop yields and the sludge application rates. During both growing seasons, leachate collected as a percentage of water applied was highest for the controls (19% from silt loam; 35% from loamy sand) and lowest from the iron sludge application (5% from silt loam; 10% from loamy sand). During the dormant period, the percentage collected was greatest (42%) from the alum sludge application.

TABLE 11. LEACHATE VOLUMES (1973 AND 1974)¹

Treatments	Rates (kg TKN/ha)	1973 Growing		1973+74 Dormant		1974 Growing		1973+74 Total	
	1973 1974	Loamy Sand	Silt Loam	Loamy Sand	Silt Loam	Loamy Sand	Silt Loam	Loamy Sand	Silt Loam
Control	0	4040	2071	1270	1553	2978	1716	8288	5340
NPK	336•112•112 400•133•133	1518	693	1481	1160	1168	784	4167	2637
Alum Sludge	300 400	3540	1618	1845	1578	1520	660	6905	3856
	600 800	3257	1736	2003	1801	972	308	6232	3845
	900 1200	3343	1534	1964	1743	920	324	6227	3601
Iron Sludge	300 400	2834	877	1519	1520	1264	524	5617	2921
	600 800	2032	701	1579	1425	1008	624	4619	2750
	900 1200	1248	658	1708	1674	780	456	3736	2788
Lime Sludge	300 400	3044	1382	1357	1337	1388	476	5789	3195
	600 800	1913	885	1263	1303	1036	448	4212	2636
	900 1200	1903	958	1336	1373	756	460	3995	2791
Standard Error ±		208		145		114		289	
Treatments		**		**		**		**	
- Control vs Others		**		*		**		**	
- NPK vs Sludges		**		**		*		**	
- Sludge Types		**		**		**		**	
- Sludge Rates		**		NS		**		**	
- Sludge Types x Rate		*		NS		**		**	
Soil Types		**		NS		**		**	
Treatments x Soil Types		**		*		**		**	

¹ (m³/ha).

* Significant at 0.05 Probability (F test).

** Significant at 0.01 Probability (F test).

NS Non Significant.

4.3.2 Leachate chemical constituents

Mean seasonal pH values as well as chemical concentrations of TKN, $\text{NH}_4\text{-N}$, $\text{NO}_3\text{-N}$, total P, soluble P, TOC, Cl, SO_4 , Ca, Mg, Na, K, Al, Fe, Mn, Cu, Zn, Ni, Cr, Pb, and Cd in leachate from the various treatments are given in Tables 41 to 62 (Appendix II). These values are compared with maximum permissible limits (MPL) for potable water, irrigation water or sewage effluent standards where available (Table 12).

The leachate values for pH, Cl, SO_4 , Mg, Fe, Cu, Zn, Cr, and Cd were within the maximum permissible limits (MPL) of the Canadian Drinking Water Standards (Canada, 1969). Although Mn and Pb values infrequently exceeded the drinking water MPL of 0.05 mg/l, these constituents as well as Al and Ni (OMOE, 1974) and Na (USDA, 1954) were always within the irrigation water MPL.

No similar water quality standards exist for TKN, total P, TOC or K. The biochemical oxygen demand (BOD_5) sewage effluent MPL (15 mg/l) was chosen as an approximate standard of comparison with values obtained for leachate TOC. Leachate samples with maximum TOC concentrations of 25 mg/l were found to have BOD_5 concentrations of approximately 15 mg/l.

Leachate maximum concentrations from sludge treatments were higher than their respective water quality MPL for $\text{NO}_3\text{-N}$ (34.6 mg/l) and Ca (242 mg/l). These values were similar to those obtained from the untreated controls during 1973, indicating that flushing of these constituents from the reconstituted lysimeter soils was a major source of these high concentrations. Water quality standards are not available for TKN or K, but maximum concentrations of these constituents from sludge treatments (1.3 mg TKN/l and 3.1 mg K/l) were comparable to the untreated controls (1.3 mg TKN/l and 2.5 mg K/l).

Leachate concentrations of both $\text{NH}_4\text{-N}$ and soluble P from sludge treatments ranged from <0.01 to 1.44 mg/l for both years. These concentrations are higher than the controls and the drinking water MPL. High concentrations of $\text{NH}_4\text{-N}$ were only observed during the 1973 growing season, dropping below the drinking water MPL of 0.5 mg/l during 1974.

TABLE 12. LEACHATE CHEMICAL CONSTITUENTS COMPARED TO WATER QUALITY STANDARDS (1973 AND 1974)

Constituents	Units	Untreated Control Leachate	Sludge Treated Leachate	Maximum Permissible Limit	Reference
pH		7.6 - 8.0	7.6 - 8.0	6.5 - 8.3	1
TKN	mg/l	0.1 - 1.3	0.1 - 1.3	-	N/A
NH ₄ -N	"	<0.01 - 0.17	<0.01 - 1.43	0.5	1
NO ₃ -N	"	0.1 - 33.3	0.1 - 34.6	10.0	1
Total P	"	0.01 - 0.73	0.01 - 0.95	1.0	3
Soluble P	"	<0.01 - 0.72	<0.01 - 1.44	0.1	1
TOC	"	5.4 - 28.3	5.9 - 25.3	15.0 (BOD)	4
Cl	"	<1 - 50	<1 - 50	150	2
SO ₄	"	12 - 175	49 - 217	500	1
Ca	"	46 - 269	54 - 242	200	1
Mg	"	11 - 35	11 - 42	150	1
Na	"	4 - 42	4 - 43	125	5
K	"	0.6 - 2.5	0.7 - 3.1	-	N/A
Al	µg/l	16 - 64	11 - 41	20 × 10 ³	2
Fe	"	50 - 240	42 - 198	300	1
Mn	"	6 - 212	8 - 521	50 ; 20 × 10 ³	1 ; 2
Cu	"	7 - 94	8 - 85	1000	1
Zn	"	6 - 93	6 - 85	5000	1
Ni	"	3 - 19	2 - 42	2000	2
Cr	"	1 - 5	1 - 12	50	1
Pb	"	9 - 58	7 - 59	50 ; 20 × 10 ³	1 ; 2
Cd	"	1 - 6	1 - 7	10	1

1. Canada (1969). (Drinking water standard).

2. OMOE (1974). (Irrigation water standard).

3. Canada/US GLWQ Agreement (1972).

4. OWRC (1970).

5. USDA (1954).

N/A Not Available.

Soluble P concentrations higher than the MPL of 0.1 mg/l were only observed from the alum sludge application and the untreated control during the 1974 growing season.

The 22 leachate constituents analyzed can be grouped into three categories based on concentration trends with time. The categories are:

1. Concentrations that never exceeded their respective MPL.
2. Concentrations that initially exceeded their respective MPL, but stabilized below their MPL during the second growing season.
3. Concentrations which exceeded their respective MPL during the second growing season.

In category 1, were pH, total P, Cl, SO₄, Mg, Na, Al, Fe, Mn, Cu, Zn, Ni, Cr, and Cd. The pH, total P, K, Cr and Cd concentrations in leachate were not affected by sludge types, rates or soil types. Concentrations of Cl, SO₄, Cu, Zn, and Ni increased with increasing rates of sludge and were highest from silt loam. Concentrations of Al, Fe and Mn were not affected by sludge types or rates. Concentrations of Al and Fe were higher from silt loam while Mn was higher from loamy sand. Concentrations of Mg and Na were not affected by sludge type or rates, but were higher from silt loam than loamy sand.

In category 2, were NO₃-N, NH₄-N, Ca, and Pb. Concentrations of TKN did not exceed 0.6 mg/l, and NO₃-N leachate concentrations stabilized to <7 mg/l during the second growing season. Concentrations of NH₄-N, Ca, and Pb did not exceed 0.12 mg/l, 90 mg/l and 37 µg/l, respectively, all below the drinking water MPL (Table 12). Concentrations of TKN and Ca were not affected by sludge types or rates. Concentrations of Ca were higher from silt loam while NO₃-N concentrations were highest from loamy sand.

In category 3, were soluble P, TOC and Mn. Soluble P concentrations were not affected by sludge rates or soil types, but the alum sludge application yielded concentrations exceeding the drinking water MPL. Concentrations of Mn were below the irrigation water MPL (OMOE, 1974), but were higher than the drinking water MPL (Canada, 1969).

Concentrations of TOC tended to increase with time. In view of the possibility that TOC may include PCB's or other carcinogenic organic compounds further study in this area is indicated.

4.4 Microbiological Analyses

4.4.1 Leachate bacterial densities

Leachates were monitored monthly from June to November, 1973 for aerobic heterotrophs and various coliform bacteria. After six months of sludge application, no differences in bacteria type or concentration due to sludge treatments were observed. The predominant types of bacteria were: Alcaligenes, Acinetobacter, Pseudomonas, Flavobacterium and Chromobacter. Most of the bacteria found in the leachate were of soil origin and ranged from 0.1 to 5.5×10^6 per ml from all treatments. The sludge microorganisms did not appear in the leachate and were apparently retained in the soils.

After two years of cumulative sludge application (2100 kg TKN/ha), the heterotrophic bacterial concentrations in leachate remained fairly constant from all treatments ranging from 0.6 to 13.0×10^5 per ml. Leachate bacteria observed during 1974 were of soil origin only.

4.4.2 Bacterial movement in soil

In April, 1974, soil cores were taken from the lysimeters to study the bacterial movement. Traditionally, coliform bacteria have been used as a model to study bacterial movement in soils (Krone, 1968). This study indicated that coliform bacteria densities accounted for less than one percent of the total heterotrophic bacteria population. Total heterotrophs were determined from the highest sludge loading to both soils (Figures 4 and 5) at depths of 2.5, 7.5, 15.0, 25.0, 37.5, and 60.0 cm.

Most of the heterotrophic bacteria (>95%) were retained in the top 15 cm layer of both soils. Sludge bacteria can survive in soils for at least one year after sludge application. Fecal coliforms and fecal streptococci were also studied in the soil profiles at the highest sludge loading rate. Most of these bacteria were retained in the top 7.5 cm layer of both soils.

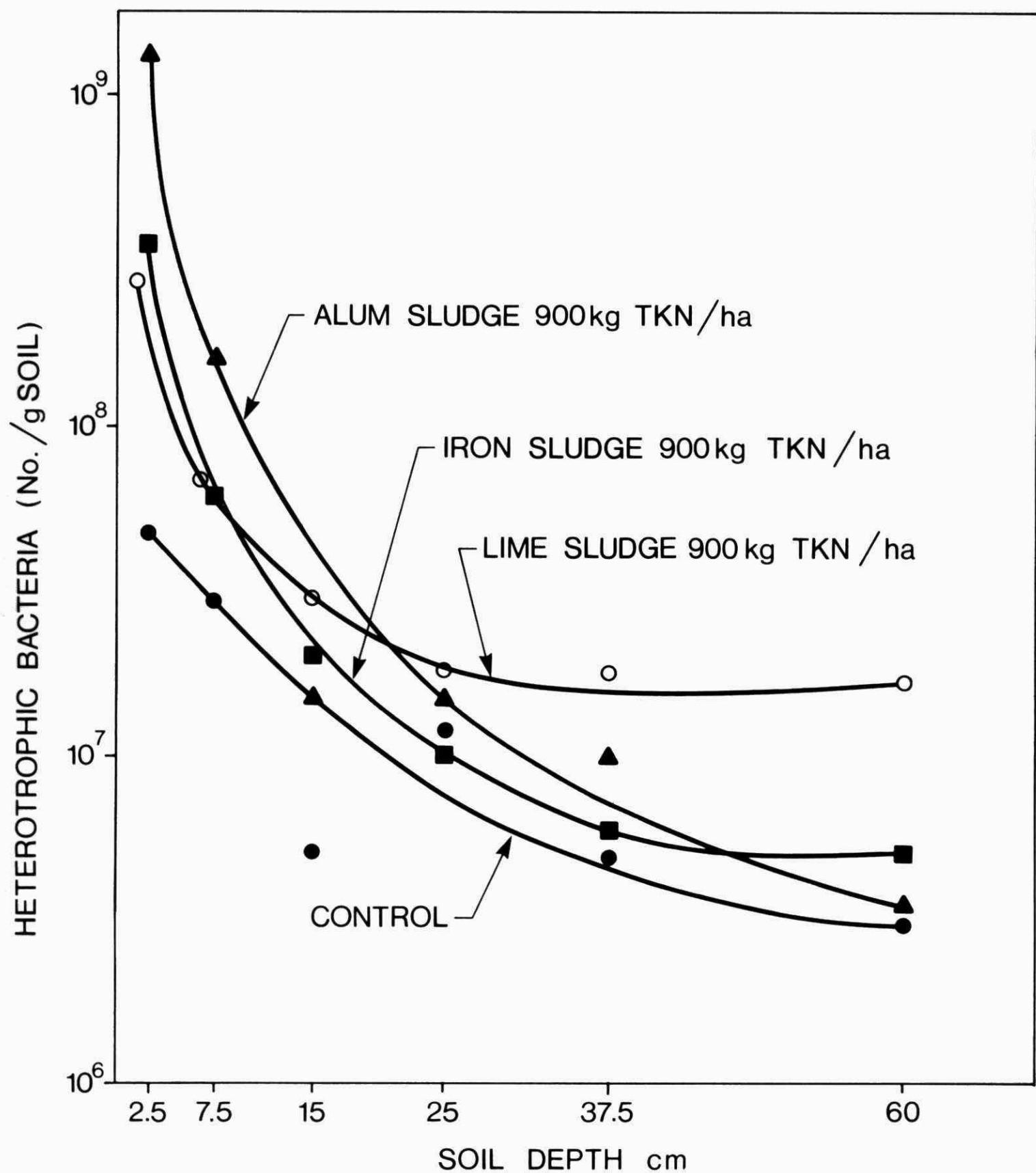


FIGURE 4 HETEROTROPHIC BACTERIA IN SLUDGED LOAMY SAND – APRIL 1974

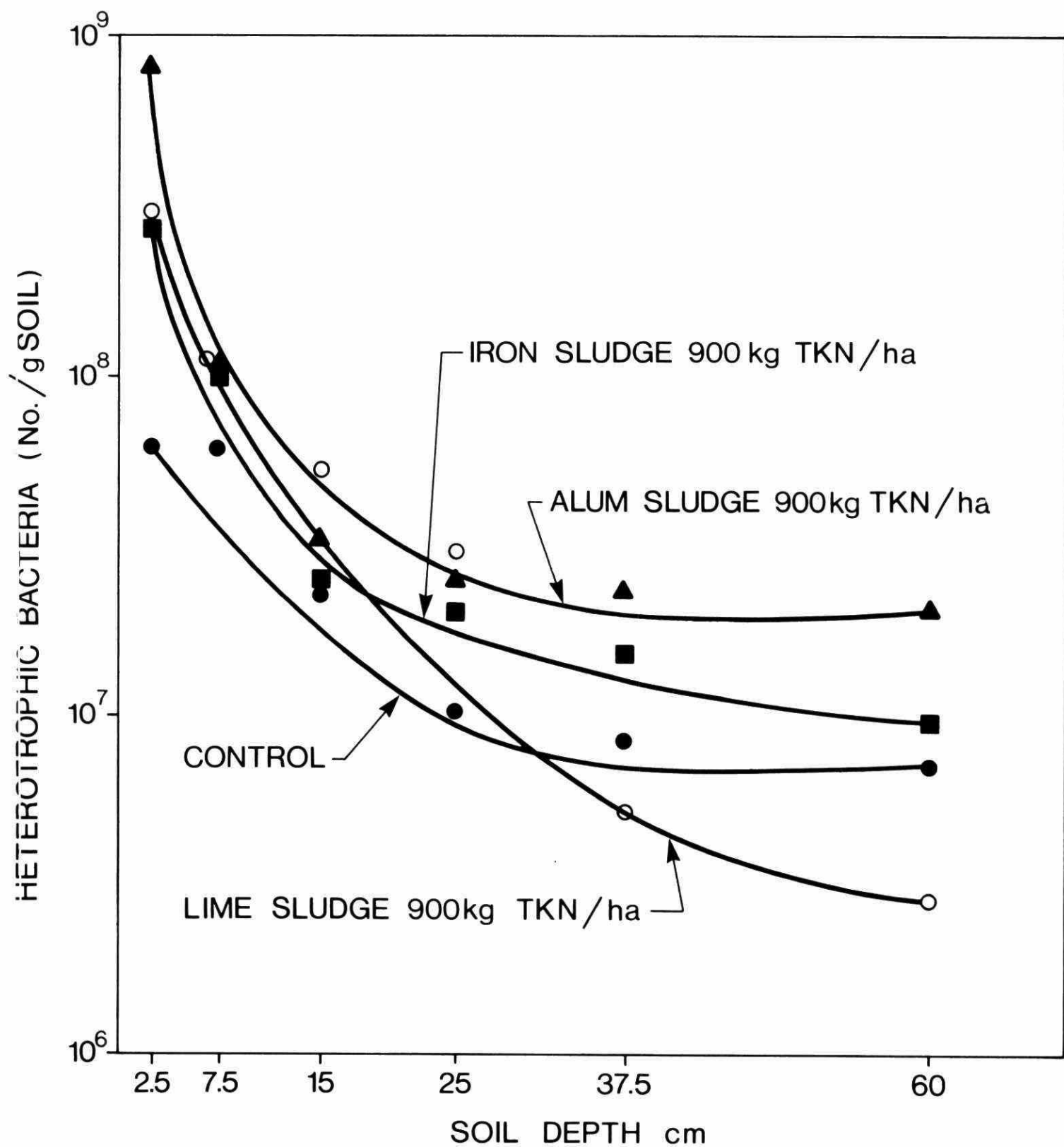


FIGURE 5 HETEROTROPHIC BACTERIA IN SLUDGED SILT LOAM – APRIL 1974

4.5 Material Balances

This lysimeter experiment was designed to provide information required to calculate theoretical material balances by stressing accurate monitoring of crop and leachate quantity and quality, and crop yields. Although soil profiles have not yet been disturbed to avoid destruction of the grass root system, soil horizons will eventually be sampled to compare calculated and actual material balances.

A complete material balance would include inputs from (a) sludge, (b) precipitation, and (c) irrigation water. Distilled water was used to irrigate the crop during both growing seasons (90 litres/lysimeter) and the contribution of chemical constituents from this source was negligible. Bulk precipitation (90 litres/lysimeter) was sampled at the Canada Centre for Inland Waters and analyzed by the Water Quality Branch of Environment Canada (Shiomi, 1975). Total precipitation inputs, based on geometric mean values for nine chemical constituents ($\mu\text{g/l}$) were compared with mean inputs from the various sludge sources. As shown in Table 13, all chemical constituents measured in precipitation accounted for less than 2.4% of the mean loadings from the various sludge sources. As the calculated inputs from sludges are considered to be accurate within $\pm 10\%$ due to sampling variability, the minor input due to precipitation was not included in these preliminary material balance calculations.

Outputs from the lysimeters included (a) leachate loss, (b) crop yield, and (c) volatilization. The first two outputs were measured quantitatively, but the unaccounted losses due to volatilization will have to be calculated after the soil horizons are sampled and analyzed.

Cumulative (1973 and 1974) material balances in both soils were calculated for N, P, K, Al, Fe, Ca, Zn, Cu, Ni, Cr, Pb, and Cd. These balances were based on the total air-dried weight of soil per lysimeter. The net change $\pm$ per lysimeter was calculated as the difference between the amount added and removed by plant uptake and leachate loss.

Material balances of these chemical constituents were also calculated on a soil concentration basis (mg/kg) for the A horizon (19 cm) of both soils. This depth is very close to the common tillage depth

(15 to 20 cm) used in calculations of maximum allowable concentrations of heavy metals that can be applied to soils (OMAF guidelines, 1976). The number of years required to double or to deplete the initial content of soil chemical constituents were calculated. The doubling time criteria for maximum metal content permitted in soil is adapted from the provisional OMAF guidelines.

TABLE 13. CHEMICAL CONSTITUENT LOADINGS FROM BULK PRECIPITATION (1973 AND 1974)

Chemical Constituents	Geometric Mean ($\mu\text{g/l}$)	Loadings per Lysimeter (mg)*	Precipitation Loading as % of mean sludge loading
N	2251	202.6	1.98
P	43	3.9	0.05
Ca	5483	493.5	0.69
Fe	17.5	1.6	0.02
Zn	68.4	6.2	1.26
Cu	4.1	0.37	0.16
Ni	2.4	0.22	2.37
Pb	9.7	0.87	0.47
Cd	0.7	0.06	1.13

* Loading = Concentration ($\mu\text{g/l}$) $\times$ 90 litres.

4.5.1 Nitrogen

Nitrogen balances are summarized in Table 14. Crop N uptake from both soils was higher in 1974 than in 1973 although N leachate losses were lower in 1974. Loamy sand had higher N leachate losses than silt loam for all treatments. The highest percentage N removals occurred at the lowest rates of iron sludge for both loamy sand and silt loam (53 and 72%) followed by lime (50 and 71%) and alum sludge (45 and 61%), respectively. If no volatilization of soil nitrogen occurred, it would take 98 and 19 years for the lowest rate of iron sludge and eight and

TABLE 14. N BALANCE IN SOILS (1973 AND 1974)

Treatments	Input to Soils (g/Lysimeter)	Loamy Sand						Silt Loam					
		g/Lysimeter			Initial Amount/Lysimeter (48.8 g)			g/Lysimeter			Initial Amount/Lysimeter (64.6 g)		
		Output		Net Change in Soil $\pm$	% Change vs Initial Soil	% Removal of Input	Years* to Double	Output		Net Change in Soil $\pm$	% Change vs Initial Soil	% Removal of Input	Years** to Double
		Plant Uptake	Leachate Loss					Plant Uptake	Leachate Loss				
Control	-	1.02	0.53	-1.55	-3.2	-	-	2.29	0.04	-2.34	-3.6	-	-
NPK	5.37	4.50	0.44	+0.43	+0.9	92	105	5.56	0.12	-0.31	-0.5	105	-
Alum - Low	5.11	1.86	0.44	+2.81	+5.7	45	16	3.03	0.10	+1.98	+3.1	61	53
Alum - Med.	10.22	2.78	0.30	+7.14	+14.6	30	6	4.22	0.06	+5.94	+9.2	42	15
Alum - High	15.33	3.79	0.57	+10.97	+22.5	28	4	5.09	0.14	+10.10	+15.6	34	8
Iron - Low	5.11	2.28	0.42	+2.42	+4.9	53	19	3.64	0.07	+1.40	+2.2	72	98
Iron - Med.	10.22	3.86	0.35	+6.01	+12.3	41	8	4.90	0.07	+5.25	+8.1	49	18
Iron - High	15.33	5.72	0.31	+9.30	+19.1	39	5	6.86	0.12	+8.35	+12.9	46	11
Lime - Low	5.11	2.09	0.47	+2.55	+5.2	50	18	3.51	0.11	+1.49	+2.3	71	89
Lime - Med.	10.22	3.34	0.35	+6.53	+13.4	36	7	4.58	0.11	+5.53	+8.6	46	16
Lime - High	15.33	4.57	0.34	+10.42	+21.4	32	4	5.66	0.23	+9.44	+14.6	38	9

* Years required to double the initial A horizon N concentration of 1150 mg/kg.

** Years required to double the initial A horizon N concentration of 2000 mg/kg.

four years for the highest rate of alum sludge to double the initial N content of silt loam and loamy sand, respectively. Nitrogen accumulation in soils may have a long term deleterious impact on groundwater quality ($\text{NO}_3\text{-N}$) which may require limiting sludge N application rates. The amount of N lost from the soil by denitrification or $\text{NH}_3\text{-N}$ volatilization cannot be determined at the present time, but will be calculated when the soil horizons are sampled and analyzed.

4.5.2 Phosphorus

Phosphorus balances are summarized in Table 15.

Crop P uptake was higher in 1974 than in 1973 on both soils. The P leachate losses were negligible from all treatments on both soils for both years. The percentage removals of P were inversely related to the sludge loading rates. If P accumulation in both soils were to continue at the present rate, it would take 23 to 45 years for the lowest rate of lime sludge and four to seven years for the highest rate of alum sludge to double the initial P content of silt loam and loamy sand, respectively.

Based on the high P loadings from sludges in excess of plant requirements, the number of years required to double the initial soil total P concentration, and the lack of long term information concerning the relationship between total and soluble P in sludged soils, lower sludge loading rates may be required if sludges are to be applied cumulatively to the same soil for many years.

4.5.3 Potassium

Potassium balances are summarized in Table 16. The cumulative net depletion of K (g K/lysimeter) was higher on silt loam than loamy sand for all treatments. For example, K removed was 24 and 10 times higher from silt loam and loamy sand, respectively than the amount of K added from the lowest rate of alum sludge.

If depletion were to continue at the present rate, it would take 492 and 170 years at the highest lime sludge application rate to deplete the total K content of loamy sand and silt loam, respectively.

TABLE 15. P BALANCE IN SOILS (1973 AND 1974)

Treatments	Input to Soils (g/Lysimeter)	Loamy Sand						Silt Loam					
		g/Lysimeter			Initial Amount/Lysimeter (327 g)			g/Lysimeter			Initial Amount/Lysimeter (2079 g)		
		Output		Net Change in Soil $\pm$	% Change vs Initial Soil	% Removal of Input	Years* to Double	Output		Net Change in Soil $\pm$	% Change vs Initial Soil	% Removal of Input	Years** to Double
		Plant Uptake	Leachate Loss					Plant Uptake	Leachate Loss				
Control	-	0.10	0	-0.10	-0.03	-	-	0.20	0	-0.20	-0.09	-	-
NPK	1.80	0.34	0	+1.46	+0.45	19.0	40	0.40	0	+1.40	+0.68	22.0	77
Alum - Low	5.15	0.25	0	+4.90	+1.50	4.8	12	0.33	0	+4.82	+2.33	6.5	22
Alum - Med.	10.30	0.36	0	+9.94	+3.03	3.5	6	0.50	0	+9.80	+4.74	4.8	11
Alum - High	15.45	0.42	0.001	+15.03	+4.60	2.7	4	0.50	0	+14.95	+7.23	3.2	7
Iron - Low	3.00	0.32	0	+2.68	+0.82	10.5	20	0.43	0.001	+2.57	+1.24	14.2	42
Iron - Med.	6.00	0.40	0.001	+5.60	+1.71	6.6	10	0.45	0	+5.55	+2.68	7.5	19
Iron - High	9.00	0.51	0	+8.49	+2.60	5.6	7	0.60	0	+8.40	+4.06	6.7	12
Lime - Low	2.80	0.28	0	+2.52	+0.77	9.9	23	0.44	0	+2.36	+1.14	15.8	45
Lime - Med.	5.60	0.39	0	+5.21	+1.60	6.9	11	0.50	0	+5.10	+2.47	8.9	21
Lime - High	8.40	0.51	0.001	+7.89	+2.41	6.1	7	0.61	0.001	+7.79	+3.82	7.3	13

* Years required to double the initial A horizon P concentration of 1520 mg/kg.

** Years required to double the initial A horizon P concentration of 2660 mg/kg.

TABLE 16. K BALANCE IN SOILS (1973 AND 1974)

Treatments	Input to Soils (g/Lysimeter)	Loamy Sand						Silt Loam					
		g/Lysimeter			Initial Amount/Lysimeter (22.33 g)			g/Lysimeter			Initial Amount/Lysimeter (13.22 g)		
		Output		Net Change in Soil $\pm$	% Change vs Initial Soil	% Removal of Input	Years* to Double	Output		Net Change in Soil $\pm$	% Change vs Initial Soil	% Removal of Input	Years** to Double
		Plant Uptake	Leachate Loss					Plant Uptake	Leachate Loss				
Control	-	1.13	0.06	-1.19	-0.05	-	-	1.93	0.05	-1.99	-0.15	-	-
NPK	1.80	2.97	0.03	-1.20	-0.05	167	484	4.83	0.04	-3.07	-0.23	270	170
Alum - Low	0.16	1.55	0.06	-1.45	-0.06	1003	400	3.87	0.05	-3.76	-0.28	2450	150
Alum - Med.	0.32	1.73	0.05	-1.46	-0.06	557	395	4.49	0.04	-4.21	-0.32	1416	133
Alum - High	0.48	1.93	0.06	-1.51	-0.07	413	385	4.35	0.04	-3.91	-0.29	915	142
Iron - Low	0.28	1.67	0.04	-1.43	-0.06	357	405	4.18	0.04	-3.94	-0.03	1507	142
Iron - Med.	0.56	1.75	0.03	-1.22	-0.05	318	469	4.04	0.04	-3.52	-0.27	729	157
Iron - High	0.84	2.10	0.04	-1.29	-0.06	254	441	4.58	0.03	-3.77	-0.28	549	147
Lime - Low	0.26	1.45	0.04	-1.23	-0.05	573	469	3.71	0.04	-3.49	-0.26	1440	160
Lime - Med.	0.52	1.74	0.03	-1.25	-0.06	341	454	3.87	0.04	-3.39	-0.26	751	163
Lime - High	0.78	1.91	0.04	-1.17	-0.05	249	492	3.93	0.04	-3.19	-0.24	508	170

* Years required to double the initial A horizon K concentration of 15000 mg/kg.

** Years required to double the initial A horizon K concentration of 17000 mg/kg.

Although total potassium content of soils is not directly related to plant available K, these depletion rates indicate that supplementary K applications are required for future grass crops to avoid growth inhibition due to K deficiencies.

4.5.4 Aluminum

Aluminum balances are summarized in Table 17. Cumulative increases (g Al/lysimeter) were similar on both soils and were related to source and rate of sludges. Highest Al accumulations in soils were observed at the highest rate of Al sludge and the lowest Al accumulations at the lowest rate of iron sludge on both soils. Less than 1% of Al applied was removed either by crop or leachate from all treatments.

If Al accumulation in soils were to continue at the present rate, it would take 650 and 606 years for the lowest rate of iron sludge compared to 33 and 31 years at the highest rate of alum sludge to double the initial Al content of silt loam and loamy sand, respectively. The potential Al toxicity to orchard grass is not considered to be a problem as the pH of both soils is greater than 7.0.

4.5.5 Iron

Iron balances are summarized in Table 18. The cumulative increases (g Fe/lysimeter) were similar for both soils and were related to sludge source and rate. Highest Fe accumulations were observed at the highest rate of iron sludge and the lowest accumulations at the lowest rate of alum sludge on both soils. Less than 2% of Fe applied was removed by crop and leachate combined for all sludge treatments. If Fe accumulation in soils were to continue at the present rate, it would take 871 and 583 years for the lowest rate of alum sludge compared to 43 and 29 years at the highest rate of iron sludge to double the initial Fe content of silt loam and loamy sand, respectively. Toxicity of Fe to orchard grass is not a major concern.

TABLE 17. AI BALANCE IN SOILS (1973 AND 1974)

Treatments	Input to Soils (g/Lysimeter)	Loamy Sand						Silt Loam					
		g/Lysimeter		Initial Amount/Lysimeter (6646 g)				g/Lysimeter		Initial Amount/Lysimeter (3651 g)			
		Output		Net Change in Soil $\pm$	% Change vs Initial Soil	% Removal of Input	Years* to Double	Output		Net Change in Soil $\pm$	% Change vs Initial Soil	% Removal of Input	Years** to Double
		Plant Uptake	Leachate Loss					Plant Uptake	Leachate Loss				
Control	-	0.01	0.001	-0.01	-<<0.01	-	-	0.01	0.001	-0.01	-<<0.01	-	-
NPK	-	0.02	0.001	-0.02	-<<0.01	-	-	0.02	0.001	-0.02	-<<0.01	-	-
Alum - Low	18.75	0.01	0.001	+18.74	+0.28	0.06	93	0.01	0.001	+18.74	+0.51	0.06	100
Alum - Med.	37.50	0.04	0.001	+37.46	+0.56	0.11	48	0.02	0.001	+37.48	+1.02	0.06	50
Alum - High	56.25	0.04	0.001	+56.21	+0.84	0.07	31	0.02	0.001	+56.23	+1.54	0.03	33
Iron - Low	2.89	0.01	0.001	+2.88	+0.04	0.38	606	0.02	0.001	+2.87	+0.08	0.73	650
Iron - Med.	5.78	0.01	0.001	+5.77	+0.08	0.19	303	0.02	0.001	+5.76	+0.16	0.36	324
Iron - High	8.67	0.01	0.001	+8.66	+0.13	0.13	202	0.02	0.001	+8.65	+0.24	0.24	215
Lime - Low	3.06	0.01	0.001	+3.05	+0.04	0.36	575	0.01	0.001	+3.05	+0.08	0.36	614
Lime - Med.	6.12	0.01	0.001	+6.11	+0.09	0.18	287	0.01	0.001	+6.11	+0.16	0.18	306
Lime - High	9.18	0.01	0.001	+9.17	+0.14	0.12	191	0.01	0.001	+9.17	+0.25	0.12	204

* Years required to double the initial A horizon Al concentration of 45000 mg/kg.

** Years required to double the initial A horizon Al concentration of 48000 mg/kg.

TABLE 18. Fe BALANCE IN SOILS (1973 AND 1974)

Treatments	Input to Soils (g/Lysimeter)	Loamy Sand						Silt Loam					
		g/Lysimeter			Initial Amount/Lysimeter (3176 g)			g/Lysimeter			Initial Amount/Lysimeter (2316 g)		
		Output		Net Change in Soil $\pm$	% Change vs Initial Soil	% Removal of Input	Years* to Double	Output		Net Change in Soil $\pm$	% Change vs Initial Soil	% Removal of Input	Years** to Double
		Plant Uptake	Leachate Loss					Plant Uptake	Leachate Loss				
Control	-	0.01	0.003	-0.01	-<<0.01	-	-	0.02	0.002	-0.02	-<<0.01	-	-
NPK	-	0.04	0.002	-0.04	-<<0.01	-	-	0.04	0.001	-0.04	-<<0.01	-	-
Alum - Low	1.55	0.02	0.002	+1.53	+0.05	1.4	583	0.03	0.001	+1.52	+0.06	2.0	871
Alum - Med.	3.10	0.03	0.002	+3.07	+0.10	1.0	290	0.03	0.001	+3.07	+0.13	1.0	430
Alum - High	4.65	0.04	0.002	+4.61	+0.15	0.9	193	0.04	0.002	+4.61	+0.20	0.9	286
Iron - Low	10.24	0.03	0.002	+10.21	+0.32	0.3	88	0.04	0.001	+10.20	+0.44	0.4	130
Iron - Med.	20.48	0.04	0.002	+20.44	+0.64	0.2	44	0.05	0.001	+20.43	+0.88	0.2	65
Iron - High	30.72	0.05	0.002	+30.67	+0.96	0.2	29	0.06	0.001	+30.66	+1.32	0.2	43
Lime - Low	3.48	0.02	0.003	+3.46	+0.11	0.7	259	0.03	0.001	+3.45	+0.15	0.9	384
Lime - Med.	6.96	0.03	0.002	+6.93	+0.22	0.5	129	0.04	0.001	+6.92	+0.30	0.6	191
Lime - High	10.44	0.04	0.001	+10.40	+0.33	0.4	86	0.05	0.001	+10.39	+0.45	0.5	127

* Years required to double the initial A horizon Fe concentration of 23000 mg/kg.

** Years required to double the initial A horizon Fe concentration of 34000 mg/kg.

4.5.6 Calcium

Calcium balances are summarized in Table 19. The cumulative increases (g Ca/lysimeter) in loamy sand were less than silt loam and were related to the higher Ca leachate losses from loamy sand. Percentage Ca removals were higher on loamy sand (1.7 to 51.8%) than silt loam (1.5 to 32.3%). If Ca accumulation were to continue at the present rate, it would take 153 and 133 years for the lowest rate of iron sludge to double the initial Ca content of loamy sand and silt loam, respectively, compared to three years at the highest rate of lime sludge for both soils. No plant toxicities or soil contamination due to Ca are reported in the literature. Increased Ca concentration may, in fact, decrease potential toxicity due to heavy metals accumulation. No major problems due to Ca accumulation in soil are, therefore, anticipated.

4.5.7 Zinc

Zinc balances are summarized in Table 20. Cumulative increases (mg Zn/lysimeter) were slightly higher in loamy sand than silt loam. The highest Zn accumulations were noted at the highest rate of iron sludge and the lowest were observed at the lowest rate of alum sludge on both soils. Crop uptake and leachate losses of Zn increased in 1974 compared to 1973 from both soils. If Zn accumulation were to continue at the present rate, it would take 30 and 31 years for the lowest rate of alum sludge to double the initial Zn content of silt loam and loamy sand, respectively, compared to four years at the highest rate of iron sludge for both soils. The zinc application rates are high compared to the initial Zn contents of loamy sand (195 mg/kg) and silt loam (100 mg/kg). The possibility of soil contamination and plant toxicity at the highest iron sludge application rates cannot be excluded. Long term cumulative sludge applications to the lysimeters should continue to enable quantification of zinc plant toxicity from sludge treatments.

4.5.8 Copper

Copper balances are summarized in Table 21. Cumulative increases (mg Cu/lysimeter) were slightly higher in loamy sand than silt

TABLE 19. Ca BALANCE IN SOILS (1973 AND 1974)

Treatments	Input to Soils (g/Lysimeter)	Loamy Sand						Silt Loam					
		g/Lysimeter			Initial Amount/Lysimeter (20628 g)			g/Lysimeter			Initial Amount/Lysimeter (7389 g)		
		Output		Net Change in Soil $\pm$	% Change vs Initial Soil	% Removal of Input	Years* to Double	Output		Net Change in Soil $\pm$	% Change vs Initial Soil	% Removal of Input	Years** to Double
		Plant Uptake	Leachate Loss					Plant Uptake	Leachate Loss				
Control	-	0.31	4.84	-5.15	-0.02	-	-	0.46	4.71	-5.17	+0.07	-	-
NPK	-	1.07	2.76	-3.83	-0.02	-	-	1.08	1.73	-2.81	+0.04	-	-
Alum - Low	17.57	0.56	4.58	+12.43	+0.06	29.2	53	0.71	3.76	+13.10	+0.17	25.4	60
Alum - Med.	35.14	0.78	4.44	+29.92	+0.14	14.8	22	0.93	3.48	+30.73	+0.41	12.5	25
Alum - High	52.71	0.99	4.37	+47.35	+0.23	10.2	14	1.09	3.52	+48.10	+0.65	8.7	16
Iron - Low	8.94	0.71	3.92	+4.31	+0.02	51.8	153	0.83	2.06	+6.05	+0.08	32.3	133
Iron - Med.	17.88	0.98	3.01	+13.89	+0.07	22.3	48	1.04	2.20	+14.64	+0.20	18.1	52
Iron - High	26.82	1.31	3.04	+22.47	+0.11	16.2	29	1.39	2.17	+23.26	+0.31	13.3	32
Lime - Low	80.78	0.60	3.63	+76.55	+0.37	5.2	9	0.84	2.88	+77.06	+1.04	4.6	10
Lime - Med.	161.56	0.96	2.96	+157.64	+0.76	2.4	4	1.13	2.11	+158.32	+2.14	2.0	5
Lime - High	242.34	1.21	3.02	+238.11	+1.15	1.7	3	1.36	2.43	+238.55	+3.23	1.5	3

* Years required to double the initial A horizon Ca concentration of 17000 mg/kg.

** Years required to double the initial A horizon Ca concentration of 19000 mg/kg.

TABLE 20. Zn BALANCE IN SOILS (1973 AND 1974)

Treatments	Input to Soils (mg/Lysimeter)	Loamy Sand						Silt Loam					
		mg/Lysimeter			Initial Amount/Lysimeter (10611 mg)			mg/Lysimeter			Initial Amount/Lysimeter (7564 mg)		
		Output		Net Change in Soil $\pm$	% Change vs Initial Soil	% Removal of Input	Years* to Double	Output		Net Change in Soil $\pm$	% Change vs Initial Soil	% Removal of Input	Years** to Double
		Plant Uptake	Leachate Loss					Plant Uptake	Leachate Loss				
Control	-	2.04	0.58	-2.62	-0.02	-	-	3.50	0.29	-3.79	-0.05	-	-
NPK	-	8.18	0.29	-8.47	-0.08	-	-	9.49	0.22	-9.71	-0.13	-	-
Alum - Low	140	3.94	0.44	+135.62	+1.3	3.1	31	5.77	0.29	+133.94	+1.8	4.3	30
Alum - Med.	280	7.01	0.36	+272.63	+2.6	2.6	15	7.81	0.29	+271.90	+3.6	2.9	15
Alum - High	420	11.24	0.29	+408.47	+3.9	2.7	10	10.73	0.29	+408.98	+5.4	2.6	10
Iron - Low	340	5.55	0.51	+333.94	+3.2	1.8	12	7.08	0.22	+332.70	+4.4	2.1	12
Iron - Med.	680	10.29	0.51	+669.20	+6.3	1.6	6	12.62	0.22	+667.16	+8.8	1.9	6
Iron - High	1020	10.22	0.36	+1009.42	+9.5	1.0	4	15.55	0.22	+1004.23	+13.3	1.5	4
Lime - Low	250	4.09	0.36	+245.55	+2.3	1.8	16	5.99	0.15	+243.86	+3.2	2.4	16
Lime - Med.	500	8.98	0.22	+490.80	+4.6	1.8	8	8.32	0.22	+491.46	+6.5	1.7	8
Lime - High	750	11.39	0.22	+738.39	+7.0	1.5	5	11.10	0.22	+738.68	+9.8	1.5	5

* Years required to double the initial A horizon Zn concentration of 105 mg/kg.

** Years required to double the initial A horizon Zn concentration of 100 mg/kg.

TABLE 21. Cu BALANCE IN SOILS (1973 AND 1974)

Treatments	Input to Soils (mg/Lysimeter)	Loamy Sand						Silt Loam					
		mg/Lysimeter		Initial Amount/Lysimeter (2272 mg)				mg/Lysimeter		Initial Amount/Lysimeter (1395 mg)			
		Output		Net Change in Soil $\pm$	% Change vs Initial Soil	% Removal of Input	Years* to Double	Output		Net Change in Soil $\pm$	% Change vs Initial Soil	% Removal of Input	Years*** to Double
		Plant Uptake	Leachate Loss					Plant Uptake	Leachate Loss				
Control	-	0.31	0.66	-0.97	-0.04	-	-	0.63	0.44	-1.07	-0.08	-	-
NPK	-	1.22	0.36	-1.58	-0.07	-	-	1.55	0.44	-1.99	-0.14	-	-
Alum - Low	100	0.60	0.51	+98.89	+4.3	1.1	5	0.99	0.36	+98.65	+7.1	1.3	8
Alum - Med.	200	1.07	0.51	+198.42	+8.7	0.8	2	1.44	0.44	+198.12	+14.2	0.9	4
Alum - High	300	1.43	0.51	+298.06	+13.1	0.6	2	1.79	0.51	+297.70	+21.3	0.8	3
Iron - Low	160	0.71	0.36	+158.93	+7.0	0.7	3	1.47	0.29	+158.24	+11.3	1.1	5
Iron - Med.	320	1.36	0.36	+318.28	+14.0	0.5	2	1.50	0.36	+318.14	+22.8	0.6	3
Iron - High	480	2.08	0.36	+477.56	+21.0	0.5	1	2.47	0.36	+477.17	+34.2	0.6	2
Lime - Low	80	0.58	0.51	+78.91	+3.5	1.4	7	0.98	0.36	+78.66	+5.6	1.7	10
Lime - Med.	160	1.11	0.36	+158.53	+7.0	0.9	3	1.33	0.36	+158.31	+11.3	1.0	5
Lime - High	240	1.42	0.36	+238.22	+10.5	0.7	2	1.72	0.44	+237.84	+17.0	0.9	3

* Years required to double the initial A horizon Cu concentration of 13 mg/kg.

** Years required to double the initial A horizon Cu concentration of 20 mg/kg.

loam. The highest Cu accumulations in both soils were noted at the highest rate of iron sludge followed by the highest rates of alum and lime sludges. Crop uptake and leachate losses of Cu were higher in 1974 than 1973 on both soils. If Cu accumulation were to continue at the present rate, it would take ten and seven years at the lowest lime sludge rate compared to two and one year at the highest iron sludge rate to double the initial Cu content of silt loam and loamy sand, respectively. Such a short doubling time is due to the low initial Cu content of loamy sand (13 mg/kg) and silt loam (20 mg/kg). Copper may, under certain conditions, become one of the most limiting metals for sludge disposal on land.

4.5.9 Nickel

Nickel balances are summarized in Table 22. Cumulative increases (mg Ni/lysimeter) were slightly lower in loamy sand than silt loam. If Ni accumulation were to continue at the present rate, it would take 188 and 99 years for the lowest rate of iron sludge compared to 39 and 21 years for the highest rate of lime sludge to double the initial Ni content of silt loam and loamy sand, respectively. Detrimental effects of Ni are not evident to date, although nickel has been reported as being more toxic to plants than either zinc or copper (Webber, 1972).

4.5.10 Chromium

Chromium balances are summarized in Table 23. Cumulative increases (mg Cr/lysimeter) were slightly lower on loamy sand than silt loam. Uptake of Cr by the crop was higher in 1974 than in 1973, but the Cr leachate losses were lower in 1974 than 1973 from both soils. If Cr accumulation were to continue at the present rate, it would take 155 and 96 years for the lowest rate of lime sludge compared to eight and five years for the highest rate of iron sludge to double the initial Cr content of silt loam and loamy sand, respectively.

TABLE 22. NI BALANCE IN SOILS (1973 AND 1974)

Treatments	Input to Soils (mg/Lysimeter)	Loamy Sand						Silt Loam					
		mg/Lysimeter			Initial Amount/Lysimeter (1163 mg)			mg/Lysimeter			Initial Amount/Lysimeter (1000 mg)		
		Output		Net Change in Soil $\pm$	% Change vs Initial Soil	% Removal of Input	Years* to Double	Output		Net Change in Soil $\pm$	% Change vs Initial Soil	% Removal of Input	Years** to Double
		Plant Uptake	Leachate Loss					Plant Uptake	Leachate Loss				
Control	-	0.06	0.36	-0.42	-0.04	-	-	0.13	0.16	-0.29	-0.03	-	-
NPK	-	0.22	0.09	-0.31	-0.03	-	-	0.23	0.12	-0.35	-0.03	-	-
Alum - Low	4	0.09	0.15	+3.76	+0.3	6.0	96	0.17	0.12	+3.71	+0.4	7.2	188
Alum - Med.	8	0.13	0.27	+7.60	+0.6	5.0	47	0.23	0.12	+7.65	+0.8	4.3	90
Alum - High	12	0.17	0.26	+11.57	+1.0	3.6	31	0.21	0.10	+11.69	+1.2	2.6	59
Iron - Low	4	0.10	0.27	+3.63	+0.3	9.2	99	0.20	0.11	+3.69	+0.4	7.8	188
Iron - Med.	8	0.17	0.34	+7.49	+0.6	6.4	48	0.25	0.11	+7.64	+0.8	4.5	90
Iron - High	12	0.27	0.17	+11.56	+1.0	3.7	31	0.26	0.16	+11.58	+1.2	3.5	59
Lime - Low	6	0.08	0.48	+5.50	+0.5	8.3	66	0.17	0.10	+5.73	+0.6	4.5	120
Lime - Med.	12	0.16	0.43	+11.41	+0.1	4.9	32	0.24	0.22	+11.54	+1.2	3.8	59
Lime - High	18	0.21	0.31	+17.48	+1.5	2.9	21	0.25	0.26	+17.49	+1.8	2.8	39

* Years required to double the initial A horizon Ni concentration of 9 mg/kg.

** Years required to double the initial A horizon Ni concentration of 17 mg/kg.

TABLE 23. Cr BALANCE IN SOILS (1973 AND 1974)

Treatments	Input to Soils (mg/Lysimeter)	Loamy Sand						Silt Loam					
		mg/Lysimeter			Initial Amount/Lysimeter (3970 mg)			mg/Lysimeter			Initial Amount/Lysimeter (2667 mg)		
		Output		Net Change in Soil $\pm$	% Change vs Initial Soil	% Removal of Input	Years* to Double	Output		Net Change in Soil $\pm$	% Change vs Initial Soil	% Removal of Input	Years** to Double
		Plant Uptake	Leachate Loss					Plant Uptake	Leachate Loss				
Control	-	0.05	0.20	-0.25	-0.01	-	-	0.10	0.35	-0.45	-0.02	-	-
NPK	-	0.16	0.27	-0.43	-0.01	-	-	0.18	0.14	-0.32	-0.01	-	-
Alum - Low	25	0.12	0.17	+24.71	+0.6	1.2	42	0.12	0.25	+24.63	+0.9	1.5	70
Alum - Med.	50	0.15	0.64	+49.21	+1.2	1.6	21	0.20	0.34	+49.46	+1.8	1.1	35
Alum - High	75	0.20	0.64	+74.16	+1.9	1.1	14	0.24	0.10	+74.66	+2.8	0.5	23
Iron - Low	72	0.12	0.58	+71.30	+1.8	0.9	15	0.14	0.15	+71.71	+2.7	0.4	24
Iron - Med.	144	0.19	0.35	+143.46	+3.6	0.4	7	0.20	0.13	+143.67	+5.4	0.2	12
Iron - High	216	0.23	0.24	+215.53	+5.4	0.2	5	0.25	0.18	+215.57	+8.1	0.2	8
Lime - Low	12	0.10	0.66	+11.24	+0.3	6.3	96	0.13	0.20	+11.67	+0.4	2.8	155
Lime - Med.	24	0.14	0.40	+23.46	+0.6	2.2	46	0.18	0.23	+23.59	+0.9	1.7	76
Lime - High	36	0.18	0.40	+35.42	+0.9	1.6	30	0.20	0.27	+35.53	+1.3	1.3	51

* Years required to double the initial A horizon Cr concentration of 27 mg/kg.

** Years required to double the initial A horizon Cr concentration of 45 mg/kg.

4.5.11 Lead

Lead balances are summarized in Table 24. Cumulative increases (mg Pb/lysimeter) were similar in both soils. Highest Pb accumulations were observed from the highest rate of iron sludge while the lowest accumulations were from the lowest rate of alum sludge on both soils. Crop Pb uptake in 1974 was higher than 1973 on both soils. If Pb accumulation were to continue at the present rate, it would take 17 and 15 years at the lowest rate of alum sludge to double the initial Pb content of loamy sand and silt loam, respectively, compared to less than one year at the highest rate of iron sludge.

4.5.12 Cadmium

Cadmium material balances are summarized in Table 25. Cumulative increases (mg Cd/lysimeter) were similar on both soils. Highest Cd accumulations were noted at the highest rate of iron sludge and the lowest accumulations were at the lowest rate of alum sludge. Crop uptake and leachate losses of Cd were generally lower in 1974 than 1973 from both soils. If Cd accumulation were to continue at the present rate, it would take less than two years for any sludge at any rate to double the initial Cd content of both the soils. Though the Cd additions to soil exceeded the OMAF tentative guideline MPL, no detrimental effects on plants or leachate quality have been observed to date. However, under these guidelines as presently drafted, Cd appears to be the most limiting sludge constituent.

4.5.13 Summary

The cumulative plant uptake of N, P, K, Al, Fe, Ca, Zn, Cu, Ni, Cr, Pb, and Cd (mg/kg soil) from both soils was highest at the high rate of iron sludge and lowest at the low rate of alum sludge. The plant uptake of these chemical constituents was slightly higher on silt loam than loamy sand.

The cumulative leachate losses of P, K, Al, Fe, Zn, Cu, Cr, Pb, and Cd (mg/kg soil) were generally negligible from both soils and no differences due to sludge source or rates were observed. Leachate

TABLE 24. Pb BALANCE IN SOILS (1973 AND 1974)

Treatments	Input to Soils (mg/Lysimeter)	Loamy Sand						Silt Loam					
		mg/Lysimeter			Initial Amount/Lysimeter (3061 mg)			mg/Lysimeter			Initial Amount/Lysimeter (1423 mg)		
		Output		Net Change in Soil $\pm$	% Change vs Initial Soil	% Removal of Input	Years* to Double	Output		Net Change in Soil $\pm$	% Change vs Initial Soil	% Removal of Input	Years** to Double
		Plant Uptake	Leachate Loss					Plant Uptake	Leachate Loss				
Control	-	0.42	0.35	-0.77	-0.02	-	-	0.75	0.66	-1.41	-0.10	-	-
NPK	-	1.31	0.50	-1.81	-0.06	-	-	2.10	0.41	-2.51	-0.18	-	-
Alum - Low	42	0.72	1.06	+40.22	+1.3	4.2	17	1.04	0.51	+40.45	+2.8	3.7	15
Alum - Med.	84	1.18	0.89	+81.93	+2.7	2.5	8	1.49	0.55	+81.96	+5.8	2.4	7
Alum - High	126	1.39	0.90	+123.71	+4.0	1.8	6	2.00	0.57	+123.48	+8.7	2.0	5
Iron - Low	187	0.72	0.74	+185.54	+6.1	0.8	4	1.63	0.36	+185.01	+13.0	1.1	3
Iron - Med.	374	1.39	0.54	+372.07	+12.2	0.5	2	1.75	0.39	+371.86	+26.1	0.6	2
Iron - High	561	2.47	0.47	+558.06	+18.2	0.5	1	2.41	0.74	+557.85	+39.2	0.6	1
Lime - Low	46	0.64	0.89	+44.47	+1.5	3.3	16	1.06	0.39	+44.55	+3.1	3.1	14
Lime - Med.	92	1.07	0.58	+90.35	+3.0	1.8	8	1.42	0.44	+90.14	+6.3	2.0	7
Lime - High	138	1.52	0.58	+135.90	+4.5	1.5	5	1.72	0.55	+135.73	+9.5	1.6	5

* Years required to double the initial A horizon Pb concentration of 18 mg/kg.

** Years required to double the initial A horizon Pb concentration of 16 mg/kg.

TABLE 25. Cd BALANCE IN SOILS (1973 AND 1974)

Treatments	Input to Soils (mg/Lysimeter)	Loamy Sand						Silt Loam					
		mg/Lysimeter			Initial Amount/Lysimeter (21 mg)			mg/Lysimeter			Initial Amount/Lysimeter (10 mg)		
		Output		Net Change in Soil $\pm$	% Change vs Initial Soil	% Removal of Input	Years* to Double	Output		Net Change in Soil $\pm$	% Change vs Initial Soil	% Removal of Input	Years** to Double
		Plant Uptake	Leachate Loss					Plant Uptake	Leachate Loss				
Control	-	0.03	0.12	-0.15	-0.7	-	-	0.04	0.09	-0.13	-1.3	-	-
NPK	-	0.04	0.06	-0.10	-0.5	-	-	0.07	0.04	-0.11	-1.1	-	-
Alum - Low	2	0.03	0.12	+1.85	+8.8	7.5	2	0.04	0.08	+1.88	+18.8	6.0	2
Alum - Med.	4	0.03	0.12	+3.85	+18.3	3.7	1	0.06	0.09	+3.65	+38.5	3.7	1
Alum - High	6	0.04	0.10	+5.86	+27.9	2.3	<1	0.09	0.09	+5.82	+58.2	3.0	<1
Iron - Low	4	0.04	0.09	+3.87	+18.4	3.2	1	0.07	0.11	+3.89	+38.9	2.7	1
Iron - Med.	8	0.05	0.07	+7.88	+37.5	1.5	<1	0.07	0.04	+7.89	+78.9	1.4	<1
Iron - High	12	0.07	0.06	+11.87	+56.5	1.1	<1	0.09	0.04	+11.87	+118.7	1.1	<1
Lime - Low	2	0.03	0.10	+1.87	+8.9	6.5	2	0.06	0.06	+1.88	+18.8	6.0	2
Lime - Med.	4	0.04	0.07	+3.89	+18.5	2.7	1	0.06	0.04	+3.90	+39.0	2.5	1
Lime - High	6	0.05	0.07	+5.88	+28.0	2.0	<1	0.06	0.05	+5.89	+58.9	1.8	<1

* Years required to double the initial A horizon Cd concentration of 0.1 mg/kg.

** Years required to double the initial A horizon Cd concentration of 0.1 mg/kg.

losses of N, Ca and Ni were higher from loamy sand than silt loam. Highest nitrogen leachate losses on loamy sand and silt loam were from the high rate of alum sludge and the high rate of lime sludge application, respectively. Leachate losses of Ca and Ni were highest from alum and lime sludges, respectively.

The highest cumulative increase in both soils of N, P, and Al occurred at the high rate of alum sludge; Fe, Zn, Cu, Cr, Pb and Cd at the high rate of iron sludge; Ca and Ni at the high rate of lime sludge.

The time required to double the initial chemical content of silt loam was generally higher than for loamy sand. On both soils, the lowest rate of iron sludge will require the longest time interval to double the initial content of N, Al, Ca and Ni, the lowest rate of lime sludge will require the maximum number of years to double the initial content of P, Cu and Cr while the lowest rate of alum sludge will require the longest time interval to double the initial content of Fe, Zn and Pb. All three sludges applied at the lowest rate will double the initial Cd content of both soils in less than two years.

The relationship between time required for doubling of the total and the "plant available" chemical constituents of these soils requires further work. This information will provide a firmer scientific basis for revision of provisional guidelines for sludge application to agricultural land.

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APPENDIX 1

Orchard Grass Chemical Constituents
Annual Means (1973 and 1974)

TABLE 26. NITROGEN CONCENTRATION (%) IN ORCHARD GRASS (MEAN OF 4 CUTS/YR)
1973 AND 1974

Treatments	Rates (kg TKN/ha)	Loamy Sand			Silt Loam		
	1973 1974	1973	1974	Mean	1973	1974	Mean
Control	0	1.98	2.07	2.03	2.36	2.16	2.26
NPK	336•112•112	2.63	2.76	2.70	2.76	2.74	2.75
	400•133•133						
Alum Sludge	300 400	2.01	1.91	1.96	2.27	1.93	2.10
	600 800	2.21	2.09	2.15	2.88	2.19	2.54
	900 1200	2.21	2.61	2.41	2.44	2.47	2.46
Iron Sludge	300 400	2.10	2.15	2.13	2.41	2.03	2.22
	600 800	2.62	2.59	2.61	2.69	2.40	2.55
	900 1200	2.69	2.90	2.80	2.77	2.66	2.72
Lime Sludge	300 400	2.38	2.28	2.33	2.47	1.80	2.14
	600 800	2.59	2.55	2.57	2.68	2.14	2.41
	900 1200	2.71	2.59	2.65	2.82	2.14	2.48

TABLE 27. PHOSPHORUS CONCENTRATION (%) IN ORCHARD GRASS (MEAN OF 4 CUTS/YR)
1973 AND 1974

Treatments	Rates (kg TKN/ha)	Rates (kg P/ha)	Loamy Sand			Silt Loam		
	1973 1974	1973 1974	1973	1974	Mean	1973	1974	Mean
Control	0	0	0.19	0.26	0.23	0.17	0.30	0.24
NPK	336•112•112	112	0.18	0.21	0.20	0.17	0.21	0.19
	400•133•133	133						
Alum Sludge	300 400	335 371	0.25	0.30	0.2	0.21	0.30	0.26
	600 800	670 742	0.25	0.30	0.28	0.24	0.31	0.28
	900 1200	1005 1113	0.22	0.31	0.27	0.20	0.27	0.24
Iron Sludge	300 400	136 274	0.19	0.38	0.29	0.22	0.34	0.28
	600 800	272 548	0.21	0.29	0.25	0.20	0.25	0.23
	900 1200	408 822	0.21	0.29	0.25	0.20	0.25	0.23
Lime Sludge	300 400	136 247	0.25	0.35	0.30	0.23	0.38	0.31
	600 800	272 494	0.23	0.31	0.27	0.22	0.31	0.27
	900 1200	408 741	0.22	0.31	0.27	0.24	0.29	0.27

TABLE 28. POTASSIUM CONCENTRATION (%) IN ORCHARD GRASS (MEAN OF 4 CUTS/YR)
1973 AND 1974

Treatments	Rates (kg TKN/ha)	Rates (kg K/ha)	Loamy Sand			Silt Loam		
	1973 1974	1973 1974	1973	1974	Mean	1973	1974	Mean
Control	0	0	2.36	1.70	2.03	3.10	2.50	2.80
NPK	336•112•112	112	2.22	1.39	1.81	2.98	1.84	2.41
	400•133•133	133						
Alum Sludge	300	11	2.34	1.10	1.72	3.07	2.22	2.65
	400	12						
	600	22	2.37	0.79	1.58	3.07	1.79	2.43
	800	24						
	900	33	2.21	0.73	1.47	3.05	1.41	2.23
	1200	36						
Iron Sludge	300	28	2.23	0.91	1.57	3.04	1.93	2.49
	400	11						
	600	56	1.96	0.68	1.32	2.80	1.33	2.07
	800	22						
	900	84	1.88	0.59	1.24	2.82	1.08	1.95
	1200	33						
Lime Sludge	300	23	2.19	0.89	1.54	2.95	2.72	2.84
	400	14						
	600	46	1.74	0.70	1.22	1.94	1.50	1.72
	800	28						
	900	69	1.00	0.60	0.80	2.45	2.11	2.28
	1200	42						

TABLE 29. CALCIUM CONCENTRATION (%) IN ORCHARD GRASS (MEAN OF 4 CUTS/YR)
1973 AND 1974

Treatments	Rates (kg TKN/ha)	Rates (kg Ca/ha)	Loamy Sand			Silt Loam		
	1973 1974	1973 1974	1973	1974	Mean	1973	1974	Mean
Control	0	0	0.65	0.70	0.68	0.48	0.55	0.52
NPK	336•112•112 400•133•133	-	0.62	0.61	0.62	0.52	0.53	0.53
Alum Sludge	300 400	380 2028	0.61	0.62	0.62	0.51	0.54	0.53
	600 800	760 4056	0.64	0.59	0.62	0.53	0.53	0.53
	900 1200	1140 6084	0.65	0.62	0.64	0.51	0.56	0.54
Iron Sludge	300 400	617 608	0.69	0.64	0.67	0.55	0.52	0.54
	600 800	1234 1216	0.65	0.64	0.65	0.50	0.55	0.53
	900 1200	1851 1824	0.65	0.67	0.66	0.51	0.56	0.54
Lime Sludge	300 400	7078 3984	0.69	0.67	0.68	0.55	0.56	0.56
	600 800	14156 7968	0.71	0.69	0.70	0.57	0.63	0.60
	900 1200	21234 11952	0.71	0.64	0.68	0.58	0.62	0.60

TABLE 30. MAGNESIUM CONCENTRATION (%) IN ORCHARD GRASS (MEAN OF 4 CUTS/YR) 1973 AND 1974

Treatments	Rates (kg TKN/ha)	Loamy Sand			Silt Loam		
	1973 1974	1973	1974	Mean	1973	1974	Mean
Control	0	0.33	0.34	0.34	0.29	0.30	0.30
NPK	336•112•112	0.38	0.36	0.37	0.33	0.34	0.34
	400•133•133						
Alum Sludge	300 400	0.35	0.38	0.37	0.30	0.32	0.31
	600 800	0.36	0.36	0.36	0.32	0.32	0.32
	900 1200	0.39	0.39	0.39	0.32	0.40	0.36
Iron Sludge	300 400	0.35	0.36	0.36	0.31	0.31	0.31
	600 800	0.37	0.38	0.38	0.33	0.36	0.35
	900 1200	0.38	0.39	0.39	0.35	0.39	0.37
Lime Sludge	300 400	0.35	0.34	0.35	0.32	0.32	0.32
	600 800	0.39	0.36	0.38	0.34	0.33	0.34
	900 1200	0.40	0.34	0.37	0.37	0.35	0.36

TABLE 31. SODIUM CONCENTRATION (%) IN ORCHARD GRASS (MEAN OF 4 CUTS/YR) 1973 AND 1974

Treatments	Rates (kg TKN/ha)	Loamy Sand			Silt Loam		
	1973 1974	1973	1974	Mean	1973	1974	Mean
Control	0	0.05	0.08	0.06	0.04	0.03	0.04
NPK	336•112•112 400•133•133	0.11	0.25	0.18	0.13	0.49	0.31
Alum Sludge	300 400	0.06	0.35	0.20	0.03	0.13	0.08
	600 800	0.10	0.47	0.28	0.05	0.29	0.17
	900 1200	0.11	0.58	0.34	0.07	0.64	0.36
Iron Sludge	300 400	0.11	0.41	0.26	0.07	0.25	0.16
	600 800	0.20	0.48	0.34	0.15	0.53	0.34
	900 1200	0.23	0.50	0.36	0.23	0.61	0.42
Lime Sludge	300 400	0.09	0.47	0.28	0.80	0.18	0.49
	600 800	0.22	0.71	0.46	0.16	0.56	0.36
	900 1200	0.30	0.77	0.53	0.19	0.63	0.41

TABLE 32. IRON CONCENTRATION ($\mu\text{g/g}$) IN ORCHARD GRASS (MEAN OF 4 CUTS/YR) 1973 AND 1974

Treatments	Rates (kg TKN/ha)	Rates (kg Fe/ha)	Loamy Sand			Silt Loam		
	1973 1974	1973 1974	1973	1974	Mean	1973	1974	Mean
Control	0	0	227	317	272	258	276	267
NPK	336•112•112 400•133•133	-	237	239	238	244	219	232
Alum Sludge	300 400	92 120	181	184	183	210	202	206
	600 800	184 240	210	211	211	187	193	190
	900 1200	276 360	221	251	236	217	217	217
Iron Sludge	300 400	750 654	270	228	249	412	203	308
	600 800	1500 1308	257	265	261	250	235	243
	900 1200	2250 1962	273	267	270	279	215	247
Lime Sludge	300 400	254 223	209	235	222	233	202	218
	600 800	508 446	215	249	232	201	204	203
	900 1200	762 669	212	242	227	217	203	210

TABLE 33. MANGANESE CONCENTRATION ($\mu\text{g/g}$) IN ORCHARD GRASS (MEAN OF 4 CUTS/YR) 1973 AND 1974

Treatments	Rates (kg TKN/ha)	Loamy Sand			Silt Loam		
	1973 1974	1973	1974	Mean	1973	1974	Mean
Control	0	239	217	228	210	245	228
NPK	336•112•112	163	114	139	141	141	141
	400•133•133						
Alum Sludge	300 400	201	121	161	199	148	174
	600 800	186	99	143	190	107	149
	900 1200	167	80	124	162	80	121
Iron Sludge	300 400	196	144	170	190	140	165
	600 800	133	97	115	137	97	117
	900 1200	141	87	114	132	85	109
Lime Sludge	300 400	172	115	144	173	133	153
	600 800	134	77	106	132	88	110
	900 1200	118	57	88	107	60	84

TABLE 34. ALUMINUM CONCENTRATION ($\mu\text{g/g}$) IN ORCHARD GRASS (MEAN OF 4 CUTS/YR) 1973 AND 1974

Treatments	Rates (kg TKN/ha)	Rates (kg Al/ha)	Loamy Sand			Silt Loam		
	1973 1974	1973 1974	1973	1974	Mean	1973	1974	Mean
Control	0	0	185	161	173	144	111	128
NPK	336•112•112 400•133•133	0	117	65	91	81	63	72
Alum Sludge	300 400	992 1577	308	65	187	138	79	109
	600 800	1984 3154	881	67	474	141	66	104
	900 1200	2976 4731	567	114	341	195	95	145
Iron Sludge	300 400	199 197	122	63	93	288	59	174
	600 800	398 394	102	74	88	78	68	73
	900 1200	597 591	160	70	115	219	57	138
Lime Sludge	300 400	88 332	79	64	72	105	62	84
	600 800	176 664	142	69	106	70	74	72
	900 1200	264 996	221	60	141	71	57	64

TABLE 35. COPPER CONCENTRATION ($\mu\text{g/g}$) IN ORCHARD GRASS (MEAN OF 4 CUTS/YR) 1973 AND 1974

Treatments	Rates (kg TKN/ha)	Loamy Sand			Silt Loam		
	1973 / 1974	1973	1974	Mean	1973	1974	Mean
Control	0	6.0	5.2	5.6	6.3	5.5	5.9
NPK	336•112•112	6.8	8.0	7.4	7.3	7.7	7.5
	400•133•133						
Alum Sludge	300 / 400	6.8	6.1	6.5	6.3	6.7	6.5
	600 / 800	9.6	9.0	9.3	7.0	7.9	7.5
	900 / 1200	8.2	9.8	9.0	7.0	9.2	8.1
Iron Sludge	300 / 400	8.4	5.4	6.9	14.8	4.9	9.9
	600 / 800	8.1	9.9	9.0	6.8	8.4	7.6
	900 / 1200	10.0	10.9	10.5	9.7	7.9	8.8
Lime Sludge	300 / 400	6.0	6.1	6.1	6.9	5.3	6.1
	600 / 800	6.3	9.2	7.8	6.7	6.7	6.7
	900 / 1200	6.5	9.3	7.9	6.9	8.4	7.7

TABLE 36. ZINC CONCENTRATION ($\mu\text{g/g}$) IN ORCHARD GRASS (MEAN OF 4 CUTS/YR) 1973 AND 1974

Treatments	Rates (kg TKN/ha)	Loamy Sand			Silt Loam		
	1973 / 1974	1973	1974	Mean	1973	1974	Mean
Control	0	41	40	41	36	38	37
NPK	336•112•112 / 400•133•133	43	53	48	42	51	47
Alum Sludge	300 / 400	41	31	36	38	42	40
	600 / 800	45	59	52	38	47	43
	900 / 1200	44	87	66	46	68	57
Iron Sludge	300 / 400	52	52	52	54	38	46
	600 / 800	52	83	68	47	78	63
	900 / 1200	59	112	86	54	68	61
Lime Sludge	300 / 400	44	44	44	41	37	39
	600 / 800	50	77	64	42	46	44
	900 / 1200	49	77	63	44	54	49

TABLE 37. NICKEL CONCENTRATION ($\mu\text{g/g}$) IN ORCHARD GRASS (MEAN OF 4 CUTS/YR) 1973 AND 1974

Treatments	Rates (kg TKN/ha)	Loamy Sand			Silt Loam		
	1973 / 1974	1973	1974	Mean	1973	1974	Mean
Control	0	1.3	1.2	1.3	1.4	1.3	1.4
NPK	336•112•112 / 400•133•133	1.0	1.0	1.0	1.4	1.0	1.2
Alum Sludge	300 / 400	1.4	0.8	1.1	1.4	1.0	1.2
	600 / 800	1.2	1.0	1.1	1.5	1.1	1.3
	900 / 1200	1.4	1.0	1.2	1.3	0.9	1.1
Iron Sludge	300 / 400	1.0	0.9	1.0	1.6	1.0	1.3
	600 / 800	1.3	1.0	1.2	1.4	1.3	1.4
	900 / 1200	1.6	1.1	1.4	1.2	0.8	1.0
Lime Sludge	300 / 400	1.1	0.7	0.9	1.4	0.8	1.1
	600 / 800	1.3	0.7	1.0	1.3	1.1	1.2
	900 / 1200	1.2	1.1	1.2	1.3	1.0	1.2

TABLE 38. CHROMIUM CONCENTRATION ($\mu\text{g/g}$) IN ORCHARD GRASS (MEAN OF 4 CUTS/YR) 1973 AND 1974

Treatments	Rates (kg TKN/ha)	Loamy Sand			Silt Loam		
	1973 / 1974	1973	1974	Mean	1973	1974	Mean
Control	0	0.7	1.5	1.1	0.6	1.9	1.3
NPK	336•112•112 / 400•133•133	0.6	1.3	1.0	0.5	1.2	0.9
Alum Sludge	300 / 400	0.8	1.5	1.2	0.6	1.3	1.0
	600 / 800	0.6	1.3	1.0	0.7	1.3	1.0
	900 / 1200	0.6	1.5	1.1	0.7	1.4	1.1
Iron Sludge	300 / 400	0.7	1.1	0.9	0.7	1.2	1.0
	600 / 800	0.8	1.5	1.2	0.6	1.5	1.1
	900 / 1200	0.5	1.6	1.1	0.5	1.8	1.2
Lime Sludge	300 / 400	0.5	1.3	0.9	0.5	1.4	1.0
	600 / 800	0.5	1.5	1.0	0.5	1.4	1.0
	900 / 1200	0.5	1.5	1.0	0.6	1.3	1.0

TABLE 39. LEAD CONCENTRATION ($\mu\text{g/g}$) IN ORCHARD GRASS (MEAN OF 4 CUTS/YR) 1973 AND 1974

Treatments	Rates (kg TKN/ha)	Loamy Sand			Silt Loam		
	1973 / 1974	1973	1974	Mean	1973	1974	Mean
Control	0	8.0	9.0	8.5	7.0	8.0	7.5
NPK	336•112•112	5.7	9.9	7.8	7.6	8.6	8.1
	400•133•133						
Alum Sludge	300 / 400	7.0	7.7	7.4	7.0	7.3	7.2
	600 / 800	10.3	8.5	9.4	6.5	8.6	7.6
	900 / 1200	8.7	9.0	8.9	7.5	11.0	9.3
Iron Sludge	300 / 400	8.5	5.7	7.1	13.4	7.6	10.5
	600 / 800	7.2	11.0	9.1	6.1	11.2	8.7
	900 / 1200	8.7	16.1	12.4	9.1	10.1	9.6
Lime Sludge	300 / 400	6.0	7.7	6.9	7.0	5.9	6.5
	600 / 800	7.5	7.8	7.7	6.6	7.1	6.9
	900 / 1200	7.0	9.5	8.3	7.3	7.8	7.6

TABLE 40. CADMIUM CONCENTRATION ($\mu\text{g/g}$) IN ORCHARD GRASS (MEAN OF 4 CUTS/YR) 1973 AND 1974

Treatments	Rates (kg TKN/ha)	Loamy Sand			Silt Loam		
	1973 / 1974	1973	1974	Mean	1973	1974	Mean
Control	0	0.74	0.17	0.46	0.58	0.20	0.39
NPK	336•112•112 / 400•133•133	0.55	0.18	0.37	0.53	0.16	0.35
Alum Sludge	300 / 400	0.56	0.17	0.37	0.44	0.18	0.31
	600 / 800	0.61	0.15	0.38	0.58	0.17	0.38
	900 / 1200	0.46	0.20	0.33	0.58	0.42	0.50
Iron Sludge	300 / 400	0.52	0.20	0.36	0.63	0.21	0.42
	600 / 800	0.53	0.24	0.39	0.48	0.21	0.35
	900 / 1200	0.58	0.27	0.43	0.57	0.23	0.40
Lime Sludge	300 / 400	0.63	0.18	0.41	0.55	0.17	0.36
	600 / 800	0.46	0.19	0.33	0.44	0.20	0.32
	900 / 1200	0.49	0.17	0.33	0.50	0.20	0.35

APPENDIX II

Leachate Chemical Constituents
Seasonal Means (1973 and 1974)

TABLE 41. LEACHATE pH VALUES (SEASONAL MEANS) 1973 AND 1974

Treatments	Rates (kg TKN/ha)	Loamy Sand				Silt Loam			
	1973 1974	1973 Growing	1973-74 Dormant	1974 Growing	Mean	1973 Growing	1973-74 Dormant	1974 Growing	Mean
Control	0	7.8	7.9	7.7	7.8	7.9	7.8	7.6	7.8
NPK	336•112•112 400•133•133	7.9	7.9	7.9	7.9	8.0	7.9	7.6	7.8
Alum Sludge	300 400	7.8	7.8	7.8	7.8	8.0	7.8	7.6	7.8
	600 800	7.8	7.8	7.7	7.8	8.0	7.9	7.6	7.8
	900 1200	7.8	7.8	7.6	7.7	7.9	7.9	7.6	7.8
Iron Sludge	300 400	7.8	7.8	7.9	7.8	7.9	7.9	7.7	7.8
	600 800	7.8	7.9	7.8	7.8	7.9	7.9	7.8	7.9
	900 1200	7.9	7.9	7.9	7.9	8.0	7.9	7.7	7.9
Lime Sludge	300 400	7.8	7.9	7.7	7.8	8.0	7.9	7.7	7.9
	600 800	7.9	7.9	7.8	7.9	7.9	7.9	7.7	7.9
	900 1200	7.8	7.8	7.7	7.8	7.9	7.9	7.7	7.9

TABLE 42. TKN CONCENTRATIONS (mg/l) IN LEACHATE (SEASONAL MEANS) 1973 AND 1974

Treatments	Rates (kg TKN/ha)	Loamy Sand				Silt Loam			
	1973 1974	1973 Growing	1973-74 Dormant	1974 Growing	Mean	1973 Growing	1973-74 Dormant	1974 Growing	Mean
Control	0	0.6	0.3	0.1	0.3	0.9	0.1	0.1	0.4
NPK	336•112•112 400•133•133	1.0	0.1	0.2	0.4	1.3	0.3	0.5	0.7
Alum Sludge	300 400	0.7	0.1	0.2	0.3	0.9	0.3	0.3	0.5
	600 800	1.0	0.2	0.2	0.5	1.0	0.4	0.6	0.7
	900 1200	1.2	0.2	0.2	0.5	1.0	0.3	0.4	0.6
Iron Sludge	300 400	0.7	0.1	0.2	0.3	0.8	0.2	0.3	0.4
	600 800	0.7	0.1	0.1	0.3	1.0	0.3	0.2	0.5
	900 1200	1.2	0.3	0.1	0.5	1.1	0.3	0.1	0.5
Lime Sludge	300 400	0.8	0.1	0.1	0.3	0.9	0.2	0.1	0.4
	600 800	0.8	0.1	0.1	0.3	0.9	0.4	0.1	0.5
	900 1200	0.8	0.3	0.4	0.5	1.3	0.5	0.6	0.8

TABLE 43. $\text{NH}_4\text{-N}$ CONCENTRATIONS (mg/l) IN LEACHATE (SEASONAL MEANS) 1973 AND 1974

Treatments	Rate (kg TKN/ha)	Loamy Sand				Silt Loam			
	1973 1974	1973 Growing	1973-4 Dormant	1974 Growing	Mean	1973 Growing	1973-4 Dormant	1974 Growing	Mean
Control	0	0.08	0.09	0.01	0.06	0.17	ND	0.02	0.06
NPK	336•112•112	0.04	0.03	0.01	0.03	0.04	0.01	0.10	0.05
	400•133•133								
Alum Sludge	300 400	ND	ND	ND	ND	0.06	0.01	0.06	0.04
	600 800	0.34	ND	ND	0.11	0.08	0.05	0.17	0.10
	900 1200	0.86	ND	ND	0.29	1.43	0.03	0.02	0.49
Iron Sludge	300 400	0.16	0.05	0.04	0.08	0.60	0.01	0.10	0.24
	600 800	0.07	ND	ND	0.02	ND	0.01	0.02	0.01
	900 1200	0.40	0.05	ND	0.15	0.04	0.12	ND	0.05
Lime Sludge	300 400	0.91	ND	0.02	0.31	ND	0.01	0.04	0.02
	600 800	0.48	ND	0.03	0.17	ND	0.06	ND	0.02
	900 1200	0.11	0.01	0.08	0.07	ND	0.06	0.13	0.06

ND = Not Detected (<0.01 mg/l).

TABLE 44. NO₃-N CONCENTRATIONS (mg/l) IN LEACHATE (SEASONAL MEANS) 1973 AND 1974

Treatments	Rate (kg TKN/ha)	Loamy Sand				Silt Loam			
	1973 1974	1973 Growing	1973-74 Dormant	1974 Growing	Mean	1973 Growing	1973-74 Dormant	1974 Growing	Mean
Control	0	24.7	0.1	0.9	8.6	6.0	0.3	0.2	2.2
NPK	336•112•112 400•133•133	33.3	3.0	6.7	14.3	18.5	1.5	1.6	7.2
Alum Sludge	300 400	24.0	0.5	0.8	8.4	11.8	0.4	0.5	4.2
	600 800	18.3	0.4	0.4	6.4	7.1	0.1	0.1	2.5
	900 1200	34.6	0.7	0.4	11.9	19.4	0.8	0.1	6.8
Iron Sludge	300 400	27.9	0.4	0.6	9.6	15.0	2.1	0.1	5.7
	600 800	31.8	0.8	1.9	11.2	8.6	2.0	0.4	3.7
	900 1200	33.9	2.2	0.8	12.3	13.5	2.7	0.2	5.5
Lime Sludge	300 400	31.9	0.3	0.8	11.0	13.9	0.7	0.1	4.9
	600 800	32.3	0.5	0.7	11.1	12.5	2.4	0.1	5.0
	900 1200	28.3	1.1	1.2	10.2	20.6	4.9	0.5	8.7

TABLE 45. TOTAL-P CONCENTRATIONS (mg/l) IN LEACHATE (SEASONAL MEANS) 1973 AND 1974

Treatments	Rates (kg TKN/ha)	Loamy Sand				Silt Loam			
	1973 1974	1973 Growing	1973-74 Dormant	1974 Growing	Mean	1973 Growing	1973-74 Dormant	1974 Growing	Mean
Control	0	0.02	0.01	0.01	0.01	0.01	0.01	0.02	0.01
NPK	336•112•112	0.09	0.01	0.01	0.04	0.01	0.01	0.73	0.25
	400•133•133								
Alum Sludge	300 400	0.16	0.01	0.01	0.06	0.07	0.01	0.01	0.03
	600 800	0.10	0.01	0.57	0.23	0.09	0.01	0.95	0.35
	900 1200	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Iron Sludge	300 400	0.16	0.01	0.01	0.06	0.03	0.01	0.01	0.02
	600 800	0.19	0.01	0.01	0.07	0.67	0.01	0.01	0.23
	900 1200	0.01	0.01	0.01	0.01	0.03	0.01	0.01	0.02
Lime Sludge	300 400	0.11	0.01	0.08	0.07	0.07	0.01	0.01	0.03
	600 800	0.01	0.01	0.01	0.01	0.07	0.01	0.01	0.03
	900 1200	0.06	0.01	0.01	0.03	0.09	0.01	0.01	0.04

TABLE 46. SOLUBLE-P CONCENTRATIONS (mg/l) IN LEACHATE (SEASONAL MEANS) 1973 AND 1974

Treatments	Rates (kg TKN/ha)	Loamy Sand				Silt Loam			
	1973 1974	1973 Growing	1973-74 Dormant	1974 Growing	Mean	1973 Growing	1973-74 Dormant	1973 Growing	Mean
Control	0	0.06	0.01	ND	0.02	ND	ND	0.05	0.02
NPK	336•112•112 400•133•133	0.24	ND	ND	0.08	ND	ND	0.72	0.24
Alum Sludge	300 400	0.40	ND	0.01	0.14	0.17	ND	ND	0.06
	600 800	0.26	ND	0.57	0.28	0.21	ND	0.95	0.39
	900 1200	ND	ND	ND	ND	ND	ND	ND	ND
Iron Sludge	300 400	0.41	ND	0.07	0.16	0.08	ND	ND	0.03
	600 800	0.43	ND	ND	0.14	1.44	ND	ND	0.48
	900 1200	0.03	ND	ND	0.01	0.08	ND	ND	0.03
Lime Sludge	300 400	0.27	ND	ND	0.09	0.17	ND	ND	0.06
	600 800	ND	0.01	ND	<0.01	0.17	0.01	ND	0.06
	900 1200	0.16	ND	ND	0.05	0.26	ND	ND	0.09

ND = Not Detected (<0.01 mg/l).

TABLE 47. TOTAL ORGANIC CARBON CONCENTRATIONS (mg/l) IN LEACHATE (SEASONAL MEANS) 1973 AND 1974

Treatments	Rates (kg TKN/ha)	Loamy Sand				Silt Loam			
	1973 1974	1973 Growing	1973-74 Dormant	1974 Growing	Mean	1973 Growing	1973-74 Dormant	1974 Growing	Mean
Control	0	5.8	5.8	5.4	5.7	9.9	7.1	7.7	8.2
NPK	336•112•112 400•133•133	6.6	6.5	11.8	8.3	9.2	8.0	28.3	15.2
Alum Sludge	300 400	7.2	6.5	9.0	7.6	7.8	8.7	20.8	12.4
	600 800	8.3	7.1	25.2	13.5	10.2	10.6	20.4	13.7
	900 1200	6.7	7.6	22.4	12.2	8.6	11.2	25.3	15.0
Iron Sludge	300 400	6.5	6.5	10.1	7.7	7.9	7.7	21.4	12.3
	600 800	6.1	7.0	19.2	10.8	8.5	7.9	12.4	9.6
	900 1200	7.3	7.9	8.4	7.9	9.0	8.9	16.5	11.5
Lime Sludge	300 400	6.6	5.9	6.5	6.3	7.8	9.5	21.4	12.9
	600 800	7.5	9.9	21.9	13.1	9.0	9.9	18.2	12.4
	900 1200	8.7	9.2	13.8	10.6	13.0	11.7	24.2	16.3

TABLE 48. CHLORIDE CONCENTRATIONS (mg/l) IN LEACHATE (SEASONAL MEANS) 1973 AND 1974

Treatments	Rates (kg TKN/ha)	Loamy Sand				Silt Loam			
	1973 1974	1973 Growing	1973-74 Dormant	1974 Growing	Mean	1973 Growing	1973-74 Dormant	1974 Growing	Mean
Control	0	21	1	0	7	34	4	3	14
NPK	336•112•112 400•133•133	33	3	13	16	50	10	5	22
Alum Sludge	300 400	20	0	2	7	43	6	7	19
	600 800	21	0	2	8	39	4	6	16
	900 1200	23	0	1	8	47	5	5	19
Iron Sludge	300 400	22	1	1	8	40	6	3	16
	600 800	28	0	1	10	43	7	4	18
	900 1200	25	2	0	9	50	10	4	21
Lime Sludge	300 400	24	1	3	9	40	6	9	18
	600 800	22	2	2	9	42	10	6	19
	900 1200	23	2	5	10	61	16	6	28

TABLE 49. SULPHATE CONCENTRATIONS (mg/l) IN LEACHATE (SEASONAL MEANS) 1973 AND 1974

Treatments	Rates (kg TKN/ha)	Loamy Sand				Silt Loam			
	1973 1974	1973 Growing	1973-74 Dormant	1974 Growing	Mean	1973 Growing	1973-74 Dormant	1974 Growing	Mean
Control	0	59	12	20	30	100	118	68	95
NPK	336•112•112 400•133•133	62	43	13	39	126	175	96	132
Alum Sludge	300 400	66	49	29	48	99	157	124	127
	600 800	75	84	28	62	134	182	141	152
	900 1200	82	126	43	84	116	196	200	171
Iron Sludge	300 400	68	49	21	46	106	155	93	118
	600 800	71	93	24	63	109	186	141	145
	900 1200	72	138	39	83	129	205	175	170
Lime Sludge	300 400	64	49	23	45	124	154	102	127
	600 800	68	135	41	81	107	198	135	147
	900 1200	70	141	36	82	137	217	185	180

TABLE 50. CALCIUM CONCENTRATIONS (mg/l) IN LEACHATE (SEASONAL MEANS) 1973 AND 1974

Treatments	Rates (kg TKN/ha)	Loamy Sand				Silt Loam			
	1973 1974	1973 Growing	1973-74 Dormant	1974 Growing	Mean	1973 Growing	1973-74 Dormant	1974 Growing	Mean
Control	0	92	46	65	68	269	59	79	135
NPK	336•112•112 400•133•133	152	60	60	91	111	76	69	85
Alum Sludge	300 400	130	60	59	83	242	77	73	131
	600 800	116	75	69	87	119	90	64	91
	900 1200	101	77	60	79	223	97	90	137
Iron Sludge	300 400	134	59	63	85	161	71	69	100
	600 800	113	73	59	82	233	94	78	135
	900 1200	141	93	69	101	147	105	87	113
Lime Sludge	300 400	101	54	58	71	224	71	62	119
	600 800	115	85	67	89	167	95	74	112
	900 1200	132	89	62	94	170	123	92	128

TABLE 51. MAGNESIUM CONCENTRATIONS (mg/l) IN LEACHATE (SEASONAL MEANS) 1973 AND 1974

Treatments	Rates (kg TKN/ha)	Loamy Sand				Silt Loam			
	1973 1974	1973 Growing	1973-74 Dormant	1974 Growing	Mean	1973 Growing	1973-74 Dormant	1974 Growing	Mean
Control	0	18	11	11	13	35	35	34	35
NPK	336•112•112 400•133•133	21	11	13	15	32	30	31	31
Alum Sludge	300 400	19	12	13	15	31	38	39	36
	600 800	18	12	14	15	33	39	36	36
	900 1200	19	12	13	15	33	36	41	37
Iron Sludge	300 400	18	11	13	14	30	29	31	30
	600 800	19	12	13	15	32	35	39	35
	900 1200	20	15	12	16	33	37	42	37
Lime Sludge	300 400	18	11	13	14	33	33	34	33
	600 800	19	14	14	16	30	37	41	36
	900 1200	19	16	15	17	35	38	38	37

TABLE 52. SODIUM CONCENTRATIONS (mg/l) IN LEACHATE (SEASONAL MEANS) 1973 AND 1974

Treatments	Rates (kg TKN/ha)	Loamy Sand				Silt Loam			
	1973 1974	1973 Growing	1973-74 Dormant	1974 Growing	Mean	1973 Growing	1973-74 Dormant	1974 Growing	Mean
Control	0	10	4	4	6	38	32	23	31
NPK	336•112•112 400•133•133	12	7	5	8	42	36	28	35
Alum Sludge	300 400	9	4	4	6	41	37	27	35
	600 800	10	4	5	6	40	33	26	33
	900 1200	9	4	4	6	43	35	31	36
Iron Sludge	300 400	9	5	4	6	36	35	28	33
	600 800	10	6	5	7	39	37	30	35
	900 1200	9	6	5	7	38	35	27	33
Lime Sludge	300 400	9	4	4	6	33	36	30	33
	600 800	9	5	5	6	33	37	31	34
	900 1200	8	6	5	6	42	37	31	37

TABLE 53. POTASSIUM CONCENTRATIONS (mg/l) IN LEACHATE (SEASONAL MEANS) 1973 AND 1974

Treatments	Rates (kg TKN/ha)	Loamy Sand				Silt. Loam			
	1973 1974	1973 Growing	1973-74 Dormant	1974 Growing	Mean	1973 Growing	1973-74 Dormant	1974 Growing	Mean
Control	0	1.5	0.6	0.7	0.9	2.3	1.3	1.2	1.6
NPK	336•112•112	1.8	0.9	0.9	1.2	2.5	1.4	1.9	1.9
	400•133•133								
Alum Sludge	300 400	1.6	0.8	0.9	1.1	2.4	1.5	2.1	2.0
	600 800	1.5	0.7	1.3	1.2	2.3	1.3	2.1	1.9
	900 1200	1.9	0.9	1.2	1.3	2.4	1.2	1.9	1.8
Iron Sludge	300 400	1.4	0.8	0.8	1.0	2.4	1.2	1.3	1.6
	600 800	1.5	0.9	0.7	1.0	3.1	1.1	1.1	1.8
	900 1200	2.0	1.2	1.3	1.5	2.2	1.3	1.2	1.6
Lime Sludge	300 400	1.5	0.8	0.8	1.0	2.3	1.2	1.3	1.6
	600 800	1.5	0.9	0.8	1.1	2.2	1.3	1.4	1.6
	900 1200	1.6	0.9	0.8	1.1	2.5	1.4	1.3	1.7

TABLE 54. ALUMINUM CONCENTRATIONS ($\mu\text{g/l}$) IN LEACHATE (SEASONAL MEANS) 1973 AND 1974

Treatments	Rates (kg TKN/ha)	Loamy Sand				Silt Loam			
	1973 1974	1973 Growing	1973-74 Dormant	1974 Growing	Mean	1973 Growing	1973-74 Dormant	1974 Growing	Mean
Control	0	17	20	18	18	26	24	21	23
NPK	336•112•112	16	18	35	23	34	27	64	42
	400•133•133								
Alum Sludge	300 400	19	22	25	22	24	23	28	25
	600 800	19	20	31	23	26	26	33	28
	900 1200	12	15	22	16	26	23	24	24
Iron Sludge	300 400	17	20	11	16	20	20	21	20
	600 800	15	20	14	16	34	26	29	30
	900 1200	15	19	11	15	33	28	14	25
Lime Sludge	300 400	16	19	25	20	23	24	14	20
	600 800	17	18	20	18	41	32	41	38
	900 1200	14	18	15	16	29	29	28	29

TABLE 55. IRON CONCENTRATIONS ($\mu\text{g/l}$) IN LEACHATE (SEASONAL MEANS) 1973 AND 1974

Treatments	Rates (kg TKN/ha)	Loamy Sand				Silt Loam			
	1973 1974	1973 Growing	1973-74 Dormant	1974 Growing	Mean	1973 Growing	1973-74 Dormant	1974 Growing	Mean
Control	0	78	52	50	60	143	89	68	100
NPK	336•112•112 400•133•133	101	55	178	111	240	141	213	198
Alum Sludge	300 400	65	55	77	65	101	68	228	132
	600 800	86	64	77	76	131	89	115	112
	900 1200	66	49	58	58	105	73	83	87
Iron Sludge	300 400	84	60	50	65	59	103	92	85
	600 800	57	52	82	64	198	122	68	129
	900 1200	49	45	47	47	116	81	89	95
Lime Sludge	300 400	97	79	72	83	59	45	86	63
	600 800	53	61	72	62	91	74	179	115
	900 1200	58	42	52	51	178	135	111	141

TABLE 56. MANGANESE CONCENTRATIONS ($\mu\text{g/l}$) IN LEACHATE (SEASONAL MEANS) 1973 AND 1974

Treatments	Rates (kg (TKN/ha)	Loamy Sand				Silt Loam			
	1973 1974	1973 Growing	1973-74 Dormant	1974 Growing	Mean	1973 Growing	1973-74 Dormant	1974 Growing	Mean
Control	0	107	99	172	126	17	10	6	11
NPK	336•112•112 400•133•133	106	115	212	144	16	11	11	13
Alum Sludge	300 400	125	79	77	94	11	8	11	10
	600 800	253	274	521	349	16	10	10	12
	900 1200	161	130	110	133	16	11	9	12
Iron Sludge	300 400	179	189	409	259	14	9	14	12
	600 800	217	187	156	187	16	12	9	12
	900 1200	120	132	231	161	29	18	19	22
Lime Sludge	300 400	107	67	60	78	11	7	30	16
	600 800	197	276	301	258	13	9	9	10
	900 1200	150	117	198	155	21	15	16	17

TABLE 57. COPPER CONCENTRATIONS ($\mu\text{g/l}$) IN LEACHATE (SEASONAL MEANS) 1973 AND 1974

Treatments	Rates (kg TKN/ha)	Loamy Sand				Silt Loam			
	1973 1974	1973 Growing	1973-74 Dormant	1974 Growing	Mean	1973 Growing	1973-74 Dormant	1974 Growing	Mean
Control	0	14	13	7	11	35	24	9	23
NPK	336•112•112 400•133•133	17	14	16	16	64	43	94	67
Alum Sludge	300 400	11	10	8	10	28	20	47	32
	600 800	15	13	40	23	37	26	77	47
	900 1200	11	11	45	22	51	34	57	47
Iron Sludge	300 400	15	12	12	13	35	25	85	48
	600 800	13	12	31	19	73	46	53	57
	900 1200	12	12	70	31	62	41	59	54
Lime Sludge	300 400	12	19	11	14	40	27	56	41
	600 800	13	13	38	21	81	51	66	66
	900 1200	14	13	38	22	80	52	78	70

TABLE 58. ZINC CONCENTRATIONS ($\mu\text{g/l}$) IN LEACHATE (SEASONAL MEANS) 1973 AND 1974

Treatments	Rates (kg TKN/ha)	Loamy Sand				Silt Loam			
	1973 1974	1973 Growing	1973-74 Dormant	1974 Growing	Mean	1973 Growing	1973-74 Dormant	1974 Growing	Mean
Control	0	9	7	6	7	23	15	7	15
NPK	336•112•112 400•133•133	11	8	31	17	50	30	93	58
Alum Sludge	300 400	8	7	11	9	15	10	55	27
	600 800	8	7	11	9	23	15	76	38
	900 1200	8	6	40	18	21	13	72	35
Iron Sludge	300 400	8	6	16	10	17	11	85	38
	600 800	10	8	27	15	39	24	51	38
	900 1200	8	6	50	21	38	23	63	41
Lime Sludge	300 400	9	12	15	12	20	13	75	36
	600 800	6	6	28	13	37	22	65	41
	900 1200	7	6	32	15	34	21	83	46

TABLE 59. NICKEL CONCENTRATIONS ($\mu\text{g/l}$) IN LEACHATE (SEASONAL MEANS) 1973 AND 1974

Treatments	Rates (kg TKN/ha)	Loamy Sand				Silt Loam			
	1973 1974	1973 Growing	1973-74 Dormant	1974 Growing	Mean	1973 Growing	1973-74 Dormant	1974 Growing	Mean
Control	0	8	6	5	6	14	10	5	10
NPK	336•112•112 400•133•133	9	7	3	6	19	12	9	13
Alum Sludge	300 400	10	7	2	6	11	8	5	8
	600 800	11	7	2	7	19	12	4	12
	900 1200	9	7	3	6	19	12	8	13
Iron Sludge	300 400	9	6	6	7	18	11	7	12
	600 800	11	8	25	15	31	13	8	17
	900 1200	9	7	42	19	25	15	20	20
Lime Sludge	300 400	13	8	11	11	14	9	14	12
	600 800	14	11	10	12	23	15	21	20
	900 1200	10	7	19	12	40	24	37	34

TABLE 60. CHROMIUM CONCENTRATIONS ($\mu\text{g/l}$) IN LEACHATE (SEASONAL MEANS) 1973 AND 1974

Treatments	Rates (kg TKN/ha)	Loamy Sand				Silt Loam			
	1973 1974	1973 Growing	1973-74 Dormant	1974 Growing	Mean	1973 Growing	1973-74 Dormant	1974 Growing	Mean
Control	0	3	3	4	3	4	4	3	4
NPK	336•112•112 400•133•133	3	3	1	2	5	4	1	3
Alum Sludge	300 400	3	3	4	3	4	4	3	4
	600 800	3	3	3	3	8	6	5	6
	900 1200	3	3	2	3	6	5	7	6
Iron Sludge	300 400	3	3	1	2	4	4	1	3
	600 800	3	4	1	3	9	7	1	6
	900 1200	4	3	2	3	11	8	3	7
Lime Sludge	300 400	3	3	2	3	6	8	5	6
	600 800	5	4	1	3	9	12	2	8
	900 1200	4	3	2	3	7	8	2	6

TABLE 61. LEAD CONCENTRATIONS ($\mu\text{g/l}$) IN LEACHATE (SEASONAL MEANS) 1973 AND 1974

Treatments	Rates (kg TKN/ha)	Loamy Sand				Silt Loam			
	1973 1974	1973 Growing	1973-74 Dormant	1974 Growing	Mean	1973 Growing	1973-74 Dormant	1974 Growing	Mean
Control	0	26	17	9	17	33	24	17	25
NPK	336•112•112 400•133•133	27	24	15	22	58	29	19	35
Alum Sludge	300 400	31	22	15	23	35	28	22	28
	600 800	29	22	37	29	37	29	27	31
	900 1200	25	21	13	20	43	34	21	33
Iron Sludge	300 400	24	19	9	17	25	21	35	27
	600 800	23	19	7	16	32	27	17	25
	900 1200	24	21	15	20	47	45	24	39
Lime Sludge	300 400	26	20	12	19	42	31	17	30
	600 800	22	20	11	18	41	32	17	30
	900 1200	26	22	16	21	59	44	19	41

TABLE 62. CADMIUM CONCENTRATIONS ($\mu\text{g/l}$) IN LEACHATE (SEASONAL MEANS) 1973 AND 1974

Treatments	Rates (kg TKN/ha)	Loamy Sand				Silt Loam			
	1973 1974	1973 Growing	1973-74 Dormant	1974 Growing	Mean	1973 Growing	1973-74 Dormant	1974 Growing	Mean
Control	0	3	2	1	2	4	3	1	3
NPK	336•112•112 400•133•133	3	4	1	3	6	4	1	4
Alum Sludge	300 400	2	3	1	2	4	3	1	3
	600 800	3	3	1	2	5	4	1	3
	900 1200	3	2	1	2	6	4	1	4
Iron Sludge	300 400	3	2	1	2	3	3	1	2
	600 800	4	3	1	3	7	4	1	4
	900 1200	4	3	1	3	5	4	1	3
Lime Sludge	300 400	4	3	1	3	4	3	1	3
	600 800	3	3	1	2	5	4	1	3
	900 1200	4	3	1	3	5	4	1	3

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